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Abstract

Classification, Paleoecology, and Biostratigraphy of Crinoids from the Stull Shale (Late Pennsylvanian) of Nebraska, Kansas, and Iowa

Roger K. Pabian and Harrell L. Strimple

Thirteen species of crinoids representing the families Diphuicrinidae, Catacrinidae, Pirasocrinidae, Erisocrinidae, Cromyocrinidae, Cymbiocrinidae, Scytalocrinidae, and Ampelocrinidae have been collected from the Stull Shale Member of the Kanwaka Formation in the Shawnee Group of the Virgil Series (Upper Pennsylvanian) from near Weeping Water and Plattsmouth, Nebraska, and near Pacific Junction, Iowa. Exposures of the Stull Shale near Melvern, Kansas, have yielded 14 species of crinoids representing the families Diphuicrinidae, Catacrinidae, Pirasocrinidae, Lophocrinidae Allagecrinidae, Cymbiocrinidae, Erisocrinidae, Apographiocrinidae, and Stellarocrinidae. All but two of the species present in the Stull Shale have been previously reported from other stratigraphic horizons, including the Vinland Shale in Kansas, the Iola and Winterset Limestones in Kansas, the Plattsburg, Oread, and Lecompton Formations of Nebraska and Iowa, the Kanawa Formation of Oklahoma, the Harpersville, Brad, and Mineral Wells Formations of Texas.

Differences in the Stull crinoid faunas between Kansas and Nebraska, as well as differences in associated faunas, indicate that two separate fossil assemblages having few species in common are being studied, although both assemblages are typical of the crinoids in the nearshore shale of a cyclothem. The Kansas assemblage may represent crinoids of a deltaic biofacies, and the Nebraska-Iowa assemblage may represent a biofacies less influenced by detritus and farther away from the source area.

Nearshore shales of midcontinent cyclothems, as described by Heckel and Baesemann (1975) and Heckel (1977), are shown to contain a different crinoid and total macroinvertebrate assemblage than do the offshore deposits of the same cyclothem. Nearshore shales contain large, ornate crinoid species and macroinvertebrates, whereas the transgressive limestones and offshore shales contain small, inornate species of crinoids and associated macroinvertebrates. These crinoid assemblages formerly were termed "Type I" and "Type II" by Pabian and Strimple (1970) but are here referred to as shallow water or nearshore and deep water or offshore assemblages respectively.

Parallelism is demonstrated for the species *Graffhamicrinus decapodos* (Strimple and Priest) and *Delocrinus vulgatus* Moore and Plummer. Three species, *Delocrinus vulgatus* Moore and Plummer, *Graffhamicrinus subcoronatus* (Moore and Plummer) and *Graffhamicrinus magnificus* (Strimple) are morphologically but not biometrically separable.

Oklahomacrinus Moore, 1939, is restricted to include only those forms with cups having basal planes formed by the medial portion of the basal plates. *Adacrinus* Pabian and Strimple, n.g., *Sardinocrinus* Pabian and Strimple, n.g., and *Kansacrinus* Pabian and Strimple n.g., are erected to include other species formerly assigned to unrestricted *Oklahomacrinus* but now excluded from restricted *Oklahomacrinus.*

Hydriocrinus acehillensis Pabian and Strimple, n. sp., is described from the Stull Shale of Nebraska.

CONTRIBUTION OF The Conservation and Survey Division, IANR, University of Nebraska–Lincoln and the University of Nebraska State Museum.

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Classification, Paleoecology, and Biostratigraphy of Crinoids from the Stull Shale (Late Pennsylvanian) of Nebraska, Kansas, and Iowa

INTRODUCTION

Most studies dealing with Pennsylvanian crinoids have been descriptive. Most interpretive work has dealt only with phylogeny. Although some biometric studies of crinoid ontogeny have been made (e. g., Brower, 1974; Pabian and Strimple, 1974b), many other areas of study have been neglected. One principal area of neglect has been the relationship of crinoid faunas to their environments of deposition. In the case of Late Pennsylvanian crinoids, few previous attempts to relate to the framework of cyclothem models have been reported in the paleontological literature. The distributions of other animals (e.g., conodonts) within the framework of the cyclothem have considerable interpretive value (see Heckel and Baesemann, 1975, Merrill and von Bitter, 1976, Heckel, 1977, Stout, 1978).

Pabian and Strimple (1970) recognized at least two distinct crinoid assemblages in Pennsylvanian rocks of Nebraska and Iowa. Small, inornate species were associated with offshore shales and transgressive limestones of cyclothems, and large, ornate species were associated with nearshore shales and regressive limestones. It was also observed, but not reported at the time, that the faunas associated with the crinoids varied considerably. Large, ornate crinoids occurred with other large, ornate invertebrates and small, inornate crinoids occurred with small, inornate invertebrates. Pabian and Strimple (1977b) also recognized that the geographic occurrences of various crinoid species were of provincial importance in interpreting Late Pennsylvanian crinoid faunas.

This study has several objectives. First, we will outline the differences in crinoids and associated fauna in the same stratigraphic unit from two widely separated geographic areas. Second, we will provide a standard for comparison of large samples of crinoids collected from different positions within a cyclothem. Third, we will attempt either to modify or to establish the known stratigraphic distributions of the many species studied. Finally, we will treat biometrically those crinoid species that occur in large numbers with widespread size-frequency distributions. These data will be helpful in understanding growth trends of many species and should prove useful in delineating a number of homeomorphic genera and species.

LOCATIONS

Specimens from Ace Hill Quarry E½ SW¼ SW¼ sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska,

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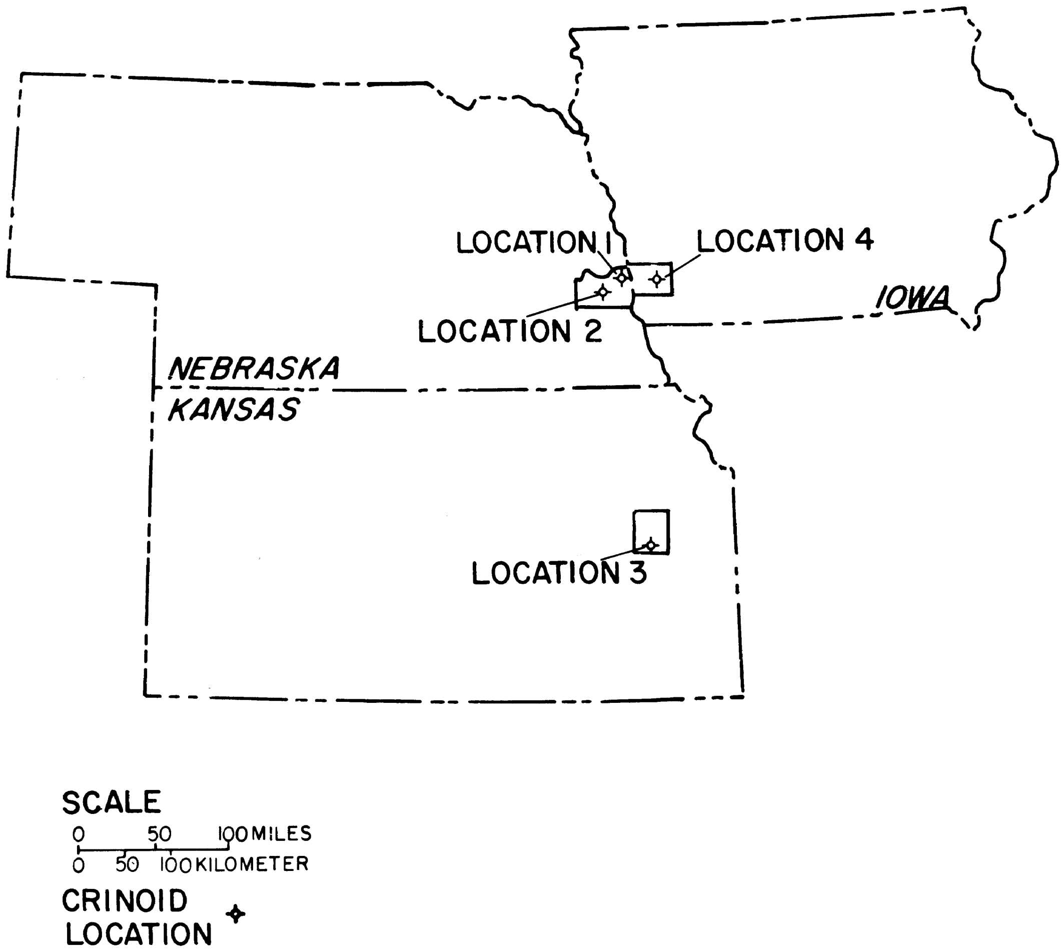

Fig. 1. Index map showing locations from which specimens were collected for this study. Location 1, Ace Hill; Location 2, Weeping Water; Location 3, Melvern, Kansas; Location 4, Pacific Junction, Iowa.

(Location 1, Fig. 1) were all collected and prepared by W. D. White of Omaha, Nebraska. Some of the other specimens from Nebraska were collected over a five-year period by the senior author from the now abandoned United Mineral Products Quarry in the SE¼ SW¼ sec. 30, T. 10 N., R. 12 E., Cass County, Nebraska, 1 mile north and 2½ miles east of Weeping Water (Location 2, Fig. 1).

Most of the Kansas specimens were collected by H. L. Strimple from an exposure situated in the NE¼ SW¼ NW¼ sec. 33, T. 17 S., R. 16 E., Osage County, Kansas, about 2 miles north and 1 mile west of Melvern (Location 3, Fig. 1). Additional specimens were collected at the same site by W. D. White, A. Allen Graffham, Christina Strimple, and Roger Pabian.

Most of the Iowa specimens were collected by W. D. White in the N½ SW¼ NW¼ sec. 29, T. 73 N., R. 43 W., near Pacific Junction, in Mills County. Crinoids were collected from several other small exposures of Stull Shale in Iowa, but none of these sites provided sufficient material to merit designation of additional numbered localities. The legal descriptions of these minor occurrences appear under material studied for the various species described in the systematic paleontology section of this study.

STRATIGRAPHIC SETTING

The Stull Shale Member of the Kanwaka Formation, defined by Moore (1932, p. 96), consists of about 30 feet of sandy shale between the top of the Clay Creek Limestone Member of the Kanwaka Formation and the base of the Spring Branch Limestone Member of the Lecompton Limestone near Stull, Douglas County, Kansas. Moore (1936, p. 172) considered the Stull Shale to be the initial deposit of the Lecompton Megacyclothem.

Schrott (1966, pp. 20—25) indicated that in Kansas and Missouri the Stull Shale is primarily sandy, micaceous, or silty shale containing numerous plant remains. Schrott (1966, p. 22) also indicated that the Stull Shale in Nebraska differs markedly from the Stull Shale in Kansas and Missouri, showing little if any detrital influx (Fig. 2). In Cass County, Nebraska, it consists of light- to dark-gray, very calcareous shales interbedded with thin limestones. Schrott also indicated that the Stull is divisible into three units that can be correlated throughout most of the outcrop area in Cass County, Nebraska.

The lowest of the three units in the Stull in Cass County, Nebraska, is a fissile to blocky, generally slightly calcareous, olive to dark-gray fossiliferous shale that contains small limestone nodules near its top. This unit ranges in thickness from 0.2 to 1.7 feet. The middle bed is a fissile to blocky, very calcareous, olive to dark-gray, very fossiliferous shale that grades laterally into a series of light-gray, thin bedded limestones intercalated with shale. The thickness of this unit ranges from 2.0 to 3.4 feet. The upper unit of the Stull consists of 1.8 to 2.0 feet of light-gray to black shales and limestones that are capped by a thin, gray brown shale containing only a few fossils. Crinoids from the middle unit of the Stull Shale in Cass County were among those studied during this investigation.

Jacobs (1973, Location 2) recognized three lithologic units and three time divisions in the Stull Shale at Weeping Water Nebraska, a site in Cass County not examined by Schrott. In ascending order, the lithologic units were designated A, B and C; the corresponding time divisions were designated as early, middle, and late. Crinoids from the upper part of unit A (late part of the early time division) and the lower part of unit B (early part of the middle time division) were also studied during this investigation. Jacobs referred the fossils in these units to a Crinoidea-encrusting algae assemblage and a *Crurithyris*-Productoidea high diversity community.

According to Jacobs (1973), the Stull at Ace Hill in Cass County contains four lithologic units. In ascending order these are: unit E, a fissile shale; unit A, a blocky shale; unit BC, a shale with limestone nodules grading upward to blocky shale, to shaly limestone, and to limestone; and unit D, shale beds intercalated with limestone beds. Units E and A correspond to the lower unit of the Stull Shale, and the lower part of the BC unit together with the D unit corresponds to the upper unit. All of the crinoids collected at Ace Hill were from the lower part of Jacobs' BC unit or the middle of the five units comprising the Stull Shale. Jacobs referred the fossil assemblage at Ace Hill to a *Crurithyris*-Productoidea high diversity assemblage. It is of interest that the crinoids in the Stull

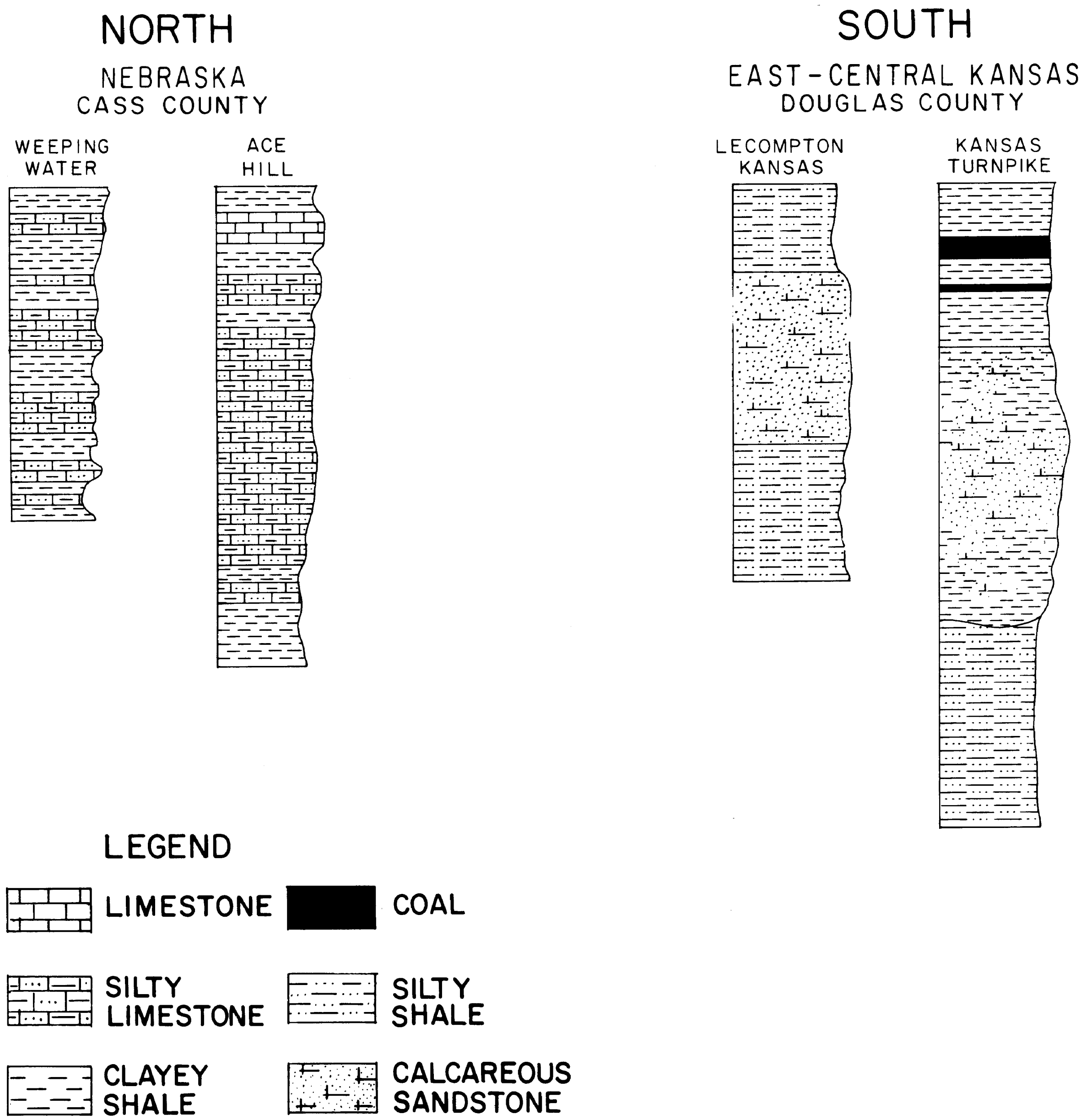

Fig. 2. Stratigraphic sections showing facies changes in the Stull Shale Member of the Kanwaka Formation from southeastern Nebraska to east-central Kansas. Sections based on data from Schrott (1966) and Jacobs (1973).

Shale of Ace Hill may differ statistically, but only slightly, from those in the Stull Shale at Weeping Water.

O'Connor (1955, pp. 16, 18) indicated that the Stull Shale is about 23 feet thick in Osage County, Kansas. He further described the member as blue-gray to gray, clayey, silty and sandy shale, and very fine, micaceous sandstone. Carbonized plant remains were reported to occur locally in the lower and middle parts, and the brachiopod, *Derbyia*, bivalves, *Leda* and *Yoldia*, and the gastropods *Bellerophon* and *B.* (*Pharkidonotus*) occur in the upper part in the northern and central parts of the county.

Johnson and Adkisson (1967, pp. 18-19) reported that the Stull Shale in Shawnee County, Kansas, ranges in thickness from 23 feet southwest of Richland to 35 feet southeast of Richland and that drill samples from southwest of Elmont penetrated about 20 feet of Stull. They described the Stull Shale as mostly light-olive-gray to medium-gray, laminated to platy, micaceous, carbonaceous siltstone and claystone that weather to light-olive-gray and locally to olive-brown. In places light- to medium-gray, very fine grained, platy to very thin-bedded micaceous sandstone is interbedded with siltstone. They also reported that the Stull contains only small plant fragments in eastern Shawnee County and vicinity and that gastropods, pelecypods, and brachiopods occur about 8 feet below the top in Osage County, which adjoins Shawnee County on the south.

Condra (1949, p. 24) indicated that it was the Stull Shale Member of the Kanwaka Formation that graded into the Elgin Sandstone of southern Kansas and northern Oklahoma. P. H. Heckel (personal communication, 1977) indicated that the shales of the Kanwaka Formation grade southward into the Elgin Sandstone. Brown (1967, p. 6, 7) further indicated that the clastic sediments in the Kanwaka Shale and in the Elgin Sandstone were derived from a land area to the south. Brown (1967, p. 3) established that open marine, shelf deposits of Virgilian age in Kansas grade southward into predominantly continental, deltaic, clastic sediments of equivalent age in north-central Oklahoma. She regarded the Elgin Sandstone of southern Kansas and Oklahoma to be part of the Kanwaka Formation.

At Melvern, Kansas, the Stull Shale consists of a platy to slightly fissile, argillaceous, sandy, slightly micaceous shale. It contains abundant, small gypsum crystals and some limonitic concretions. Although fossils are abundant, they are deeply weathered. Many show signs of wear and abrasion or corrosion. The presence of gypsum and limonite as well as the eroded nature of the fossils indicate that the sediments comprising the Stull Shale at Melvern were exposed to subaerial weathering before they were buried beneath younger deposits. Possibly erosion of the fossils at Melvern was due to the fossils having been reworked and/or transported. Some crinoid crowns from the Stull Shale at Melvern, Kansas, are enclosed in limonitic concretions (Fig. 27a). The differences in fossils in the Stull Shale of Kansas and Nebraska may reflect differences in the distances from the source area and whether the sediments were emergent before burial and subsequent lithifaction.

PALEOECOLOGY AND ASSOCIATED FAUNA

The Stull Shale in Nebraska and Iowa contains, in addition to crinoids, a large and diversified fauna of megascopic fossil invertebrates and a few fossil fish (Pabian 1970, pp. 149–152). (See Table 1.) The fossils from the Stull Shale at Weeping Water show little, if any, evidence of having been transported. Moreover, some of the trilobites are complete and some of the crinoids have arms intact. It has not been determined, however, whether the sediments containing the fossil assemblage in the Stull Shale at Weeping Water have been winnowed to any degree.

Pabian and Strimple (1970) indicated that two distinct crinoid populations, called "Type I" and "Type II," occur in the Pennsylvanian rocks of southeastern Nebraska and southwestern Iowa. Type I consists of large, ornate inadunate species; Type II consists of small, inornate species. Only a very few species of crinoids or associated fossils are common to both populations. Crinoid collections from other Pennsylvanian units of both Missourian and Virgilian ages show that different paleoenvironments account for the dissimilarity of faunas. Pabian and Strimple (1970) indicated that the two contrasting populations were temperature-controlled; Heckel and Pabian (1981, p. 281) indicated that large, ornate inadunate

TABLE 1
ASSOCIATED MACROFAUNA FROM THE STULL SHALE MEMBER OF THE KANWAKA FORMATION IN SOUTHEASTERN NEBRASKA AND EASTERN KANSAS

PHYLUM CLASS GENUS, SPECIES	CASS COUNTY, NEBRASKA			OSAGE, DOUGLAS COUNTIES, KANSAS		
	(1)	(2)	(3)	(4)	(5)	(6)
PROTOZOA						
Fusulines						
COELENTERATA						
ANTHOZOA						
Lophophyllidium	x	x		x		
Syringopora	x					
SCYPHOZOA						
Conularid	x					
ECTOPROCTA						
Fenestella	x			x		
Rhombopora	x			x		
Cyclotrypa	x					
Fistulipora				x		
Ramose forms		x				
Fenestrate forms		x				
Encrusting forms		x		x		
BRACHIOPODA						
INARTICULATA						
Lingula	x		x			
Orbiculoidea	x					
ARTICULATA						
Composita	x	x	x	x		
Neospirifer	x	x		x		
Punctospirifer	x	x	x	x		
Hustedia	x	x	x	x		
Crurithyris	x	x	x			
Cancrinella	x	x	x			
Linoproductus	x	x	x			
Antiquatonia	x	x	x			
Reticulatia		x	x			
Juresania	x	x	x	x		x
Hystriculina		x	x			
Derbyia	x	x	x	x	x	
Schuchertella	x			x		
Lissochonetes		x	x			
Neochonetes	x	x	x	x		
Leptalosia			x			
Wellerella	x	x	x			x
Meekella			x			
Rhipidomella				x		
Enteletes			x			
Beecheria	x	x	x			
Phricodothyris		x				
MOLLUSCA						
BIVALVIA						
Nucula		x				
Nuculana				x		

continued

TABLE 1
continued

PHYLUM CLASS GENUS, SPECIES	CASS COUNTY, NEBRASKA			OSAGE, DOUGLAS COUNTIES, KANSAS		
	(1)	(2)	(3)	(4)	(5)	(6)
MOLLUSCA						
BIVALVIA						
Leda					x	
Edmondia	x			x		x
Astartella				x		x
Clavicosta		x				
Acanthopecten		x				
Aviculopecten		x		x		x
Paleoyoldia				x	x	
Schizodus				x		
Wilkingia	x			x		
Myalina				x		
Myalinid, Sp. A	x					
Steinkern, Sp. B	x					
Steinkern, Sp. C	x					
Pecten, Sp. D.		x				
GASTROPODA						
Donaldina		x				
Platyceras	x					
Naticopsis	x					
Meekospira	x			x		
Straparollus				x		
Hemizyga				x		
Orthonema				x		
Anematina				x		
Palaeostylus				x		
Phymatopleura				x		x
Knightites				x		
Bellerophon				x	x	
Steinkern, Sp. A	x					
Steinkern, Sp. B	x					
Steinkern, Sp. C	x					
NAUTILIDA						
Pseudorthoceras				x		
Mooreoceras				x		
ARTHROPODA						
TRILOBITA						
Ameura	x	x				
Ditomopyge	x			x		
ECHINODERMATA						
CRINOIDEA						
Delocrinus vulgatus	x					
D. Sp. cf. D. hemisphericus				x		
Endelocrinus tumidus spinosus				x		
Pyndaxocrinus separatus				x		
P. sp. *gerdesi*	x					
Cathetocrinus stullensis	x					

continued

TABLE 1
continued

PHYLUM CLASS GENUS, SPECIES	CASS COUNTY, NEBRASKA			OSAGE, DOUGLAS COUNTIES, KANSAS		
	(1)	(2)	(3)	(4)	(5)	(6)
ECHINODERMATA						
CRINOIDEA		x				
Arrectocrinus iowensis	x					
Sublobalocrinus kaseri	x					
Graffhamicrinus magnificus	x			x		
G. subcoronatus	x			x		
G. sp.	x					
Erisocrinus typus				x		
E. sp. cf. *terminalis*				x		
Oklahomacrinus supinus	x					
Moundocrinus sp.	x					
Plaxocrinus sp. cf. *crassidiscus*	x					
Vertigocrinus gloukosensis	x					
Sciadiocrinus humilis	x			x		
S. sp. cf. *disculus*				x		
Triceracrinus facilis				x		
Stenopecrinus sp. cf. *planus*				x		
Parulocrinus sp. cf. blairi	x					
Aglaocrinus compactus	x					
Bathronocrinus sp.				x		
Stellarocrinus stillativus				x		
Apographiocrinus virgilicus				x		
Hydriocrins acehillensis	x					
Elibatocrinus sp. cf. *catactus*	x					
Kallimorphocrinus graffhami				x		
CHORDATA						
VERTEBRATA						
Petalodus	x					
Orodus	x					
Cladodus	x					
Ctenoptychius	x					
Janassa				x		

Sources: (1) Collected by Pabian, Strimple, White. (2) Schrott, 1966. (3) Dunbar & Condra, 1932. (4) Author's collections. (5) O'Connor, 1956. (6) Schrott, 1966.

crinoid species occur in the upper parts of regressive limestones and in marine parts of nearshore shales whereas small, inornate species of both inadunate and flexible crinoids occur near the top of the transgressive limestone, the non-black portions of offshore shales, and in the lower part of the regressive limestone of the cyclothemic model proposed by Heckel and Baesemann (1975) and Heckel (1977). The Type I crinoid populations are here referred to as shallow-water or nearshore crinoid assemblages because of their stratigraphic position in the cyclothem. For the same reason, the Type II crinoid assemblages are here referred to as deep-water or offshore crinoid assemblages.

Heckel and Baesemann (1975) indicated that an outside or nearshore shale consists of mostly fresh-water silty to sandy shale that locally includes sandstones, coals, and underclays and has a marine shale at its top. The Stull Shale in Kansas not only fits this description but in large part appears to be a nearshore deposit that was emergent at times. By contrast, the Stull Shale in Nebraska is a marine shale at all outcrops examined and exhibits none of the characteristics of sometimes emergent, nearshore deposits, such as weathering. Crinoid populations from the Stull Shale in both Nebraska and Kansas consist primarily of large, ornate species. Such crinoid populations are present in the upper Winterset Limestone Member of the Dennis Formation near La Platte, Nebraska, and Coffeyville, Kansas; the upper part of the Stoner Limestone Member of the Stanton Formation in Cass and Sarpy counties, Nebraska, and Wilson and Montgomery counties, Kansas; the upper part of the Ervine Creek Limestone Member of the Deer Creek Formation in Cass County, Nebraska, and Fremont County, Iowa; the Curzon Limestone Member of the Topeka Formation in Cass County, Nebraska; and the Coal Creek Limestone Member of the Topeka Formation in Cass County, Nebraska, Fremont County, Iowa, and Greenwood County, Kansas. All of the above units are interpreted as regressive limestones.

Pabian and Strimple (1979, p. 424) gave a detailed account of a crinoid fauna from the transgressive limestone-offshore shale facies of the Plattsburg Formation exposed near Altoona, Kansas. All of the crinoid species were small inornate, inadunates, or flexibles. Unpublished data based on collections made by the authors and by W. D. White show that small, inornate crinoids occur in the Hickory Creek Shale Member of the Plattsburg Formation, and the Captain Creek Limestone Member of the Stanton Formation, exposed near Wayside, Kansas; the Kiewitz Shale Bed in the Stoner Limestone Member of the Stanton Formation exposed near Louisville, Nebraska; the basal limestone bed in the South Bend Limestone Member of the Stanton Formation, exposed near Louisville, Nebraska, and Elk City, Kansas; and the basal Ervine Creek Limestone Member of the Deer Creek Formation, near Weeping Water, Nebraska. All of the above units are interpreted as transgressive limestone or offshore shale facies. Sanders (1971) indicated that in deeper water (which typifies the depositional environment of the transgressive cyclothem facies), with long-term stability of physical factors such as oxygen supply and temperature at the time of maximum transgression, delicate ecosystems become established with the maximum number of available niches. These factors account for maximum diversity of faunas near the offshore shale facies. Thus, we interpret the crinoid assemblages found near the top of the transgressive limestone or in the non-black portions of the offshore shales, or near the base of the regressive limestone as representing stable, deep, probably cold-water environments.

Pabian and Strimple (1974b, 1980a) reported large, ornate species of crinoids in several nearshore shales and regressive limestones in Nebraska and Iowa, including the following units: the Haskell Limestone Member of the Cass Formation; the Plattsmouth Limestone Member of the Oread Formation; the Doniphan Shale Member of the Lecompton Formation; the Ervine Creek Limestone Member of the Deer Creek Formation; and the Coal Creek Limestone Member of the Topeka Formation. On the basis of these occurrences, we interpret the nearshore shale and regressive limestone crinoids as representing shallow, well-oxygenated, probably warm-water assemblages. With the exception of this study, Pabian and Strimple have not yet extended their studies of crinoid assemblages into the Virgilian units of Kansas. However, most of the crinoid fossils in the Stull Shale at Melvern, Kansas, are large, ornate species that we believe are common to the shallow, warm-water assemblages. Fossils of two, common, offshore crinoid species, *Apographiocrinus virgilicus* and *Kallimorphocrinus graffhami*, have been found at Melvern, Kansas, but not in sufficient numbers to warrant deep water interpretations. Similarly, a large, ornate species may occasionally be found in an offshore assemblage. The trilobite, *Ditomopyge scitula*, is usually most abundant in the offshore facies of the cyclothem, but it occurs in the Stull Shale at Melvern, Kansas, and at Weeping Water, Nebraska.

O'Connor (1955, p. 18) noted a sparse invertebrate fauna in the Stull Shale of Osage County, Kansas. (See Table 1.) Schrott (1966, Plate II) reported a sparse marine invertebrate fauna from the Stull Shale in nearby Douglas County, Kansas; he also indicated that fossil land plants are abundant in the same location. All of the forms reported by Schrott are thought to have preferred shallow water.

Schrott (1966, Plate II) described a more diversified fauna from the Stull Shale in Cass County, near Weeping Water, Nebraska and these are interpreted as shallow water forms. (See Table 1.) Schrott collected a similar but not identical fauna from the Stull in the Queen Hill Quarry at Plattsmouth, Nebraska.

Jacobs (1973) recognized several important fossil communities and assemblages in the Stull Shale of Nebraska and Iowa. He indicated that at Weeping Water (Jacobs' Location 2) the crinoids were a part of the Crinoidea-encrusting algae assemblage and a *Crurithyris*-Productoidea high diversity assemblage. Although he did not assign the productoids to genera, Jacobs indicated that *Juresania* was an important constituent of the fauna. In addition to *Crurithyris* he reported the brachiopods *Composita*, *Derbyia*, *Neospirifer*, and *Neochonetes*; the infaunal bivalves *Wilkingia* and *Edmondia*; and the vagile, high-spired gastropod *Donaldina*.

In the fall of 1974 we collected crinoids and associated fossils from the Stull Shale at Melvern, Kansas. Although poorly preserved and deeply weathered, 42 genera were identified by the authors (Table 1).

Dunbar and Condra (1932, Table 1) reported 24 brachiopod species, representing 19 genera, from the Kanwaka Shale, which in current usage includes the Stull Shale as its top member. Most of the species reported by Dunbar and Condra have been collected from the Stull Shale in both Nebraska and Kansas. The presence of *Derbyia crassa, Juresania nebrascensis, Crurithyris planoconvexa, Punctospirifer kentuckyensis, Composita ovata*, and *C. subtilita* in the Stull Shale in both areas possibly indicates that detrital influx from a nearby source had less influence on brachiopods than on crinoids.

BIOSTRATIGRAPHIC AND BIOGEOGRAPHIC CRINOID DISTRIBUTION

From their studies of deep water, or offshore, crinoid assemblages occurring in the Wyandotte, Plattsburg, and Stanton Formations, Pabian and Strimple (1977b, p. 20) and Pabian (1979, p. 75) concluded that Late Pennsylvanian crinoids exhibited strong provincialism and gave detailed descriptions of deep water or offshore assemblages of Nebraska, Kansas, Oklahoma, and Illinois. Thus, it becomes important to establish whether shallow water or nearshore assemblages showed provincialism to the same degree that the deep water assemblages did and to determine whether the boundary between the nearshore and the offshore environments during deposition of a cyclothem was well defined or indefinite. If these determinations are made, the geological structures or other natural barriers that caused this provincialism might be identifiable and the ways in which those barriers affected the faunal distributions might be better understood.

Most of the crinoid species reported here have been described from other geographic localities. The following information is presented as an aid to establishing stratigraphic ranges and geographic distributions of Pennsylvanian crinoids.

Delocrinus vulgatus Moore and Plummer has been reported from several locations. The holotype was collected from the Saddle Creek Limestone Member of the Harpersville Formation in the Cisco Group (=Virgil Series), Young County, Texas; paratypes are from the Harpersville Formation in Stephens and Young counties, Texas and from the Brownville Limestone Member of the Kanawa Formation in the Virgil Series, near Strohm, Osage County, Oklahoma. Pabian and Strimple (1974a, p. 267) reported *D. vulgatus* from the Plattsmouth Limestone Member of the Oread Formation in the Shawnee Group of the Virgil Series, Cass County, Nebraska, and also (1974b, p. 14) from the Calhoun Shale in the Shawnee Group of the Virgil Series, Elk County, Kansas. Pabian and Strimple (1980a, p. 11) reported additional occurrences of *D. vulgatus* from the Plattsmouth Limestone Member, Oread Formation; the Spring Branch Limestone, Doniphan Shale and Beil Limestone Members of the Lecompton Formation, and the Ervine Creek Limestone Member of the Deer Creek Formation. All occurrences were in the Shawnee Group of the Virgil Series, Cass County, Nebraska, and Montgomery County, Iowa. Both Strimple (1949b, p. 340) and Pabian and Strimple (1973, p. 17) indicated that at least the paratype of *D. vulgatus* collected in Osage County, Oklahoma, was not conspecific with the holotype. That paratype (KU 4584 = USNM 104969) was assigned to *D. brownvillensis* by Strimple (1949b, pp. 340–341).

Existing collections indicate that the upper limit of the stratigraphic range of *D. vulgatus* is the top of the Brownville Limestone, Virgil Series. Possibly later collections will extend the stratigraphic range upward.

Graffhamicrinus subcoronatus (Moore and Plummer) was originally designated as *Delocrinus subcoronatus* by Moore and Plummer (1940, pp. 280–282) from the Keechi Creek Shale and Sandstone Member of the Mineral Wells Formation in the Strawn Group of the Missouri Series, Palo Pinto County, Texas. Pabian and Strimple (1974b, p. 271) subsequently reported it from the Stanton Formation in the Lansing Group of the Missouri Series and from the Oread Formation in the Shawnee Group of the Virgil Series, Cass County, Nebraska. Additional occurrences of this species given by Pabian and Strimple (1974b, p. 15) include the Haskell Limestone Member of the Cass Formation in the Douglas Group of the Virgil Series, Cass County, Nebraska, and the Hogshooter Limestone of the Kansas City Group in the Missouri Series, Montgomery County, Kansas. Pabian and Strimple (1980a, p. 5) reported additional occurrences of *G. subcoronatus* from the Shoemaker Limestone Member, Cass Formation, in the Douglas Group of the Virgil Series; the Plattsmouth Limestone Member of the Oread Formation; the Kanwaka Shale Formation; the Spring Branch Limestone, Doniphan Shale and Beil Limestone Members of the Lecompton Formation; and the Ervine Creek Limestone Member of the Deer Creek Formation. All were in the Shawnee Group of the Virgil Series in Montgomery and Mills counties, Iowa, and Cass County, Nebraska.

Graffhamicrinus magnificus (=*Delocrinus magnificus*) was described by Strimple (1947, pp. 3–5) from the Haskell Limestone Member of the Cass Limestone in the Douglas Group of the Virgil Series near Homewood, Kansas. Strimple (1971a, p. 998) reported it from the Vinland Shale Member of the Stranger Formation in the Douglas Group of the Virgil Series, and Pabian and Strimple (1974a, p. 271) reported it from the Beil Limestone Member of the Lecompton Limestone Formation in the Shawnee Group of the Virgil Series near Weeping Water, Nebraska. Pabian and Strimple (1974b, pp. 15, 35) also reported this species from the Haskell Limestone Member of the Cass Limestone in the Douglas Group of the Virgil Series, near Homewood, Kansas, and from the Ervine Creek Limestone Member of the Deer Creek Formation in the Shawnee Group of the Virgil Series, Cass County, Nebraska. Pabian and Strimple (1980a, p. 5) listed additional occurrences of *G. magnificus* in the Haskell Limestone Member of the Cass Formation in the Douglas Group of the Virgil Series; the Plattsmouth Limestone Member of the Oread Formation; the Doniphan Shale and Beil Limestone Members of the Lecompton Formation; and the Ervine Creek Limestone Member of the Deer Creek Formation. All were in the Shawnee Group of the Virgil Series, Cass County, Nebraska.

Oklahomacrinus supinus (Moore, 1939, pp. 258–261) has been described from the upper part of the Brownville Member of the Kanawa Formation in the Virgil Series, near Strohm, Oklahoma, and it is reported from the middle part of the Stull Shale Member of the Kanwaka Formation in the Shawnee Group of the Virgil Series, near Weeping Water, Nebraska; thus, the tentative stratigraphic range of this species is from the middle part of the Stull Shale to the upper part of the Brownville Limestone. Pabian and Strimple (1980a, p. 16) also reported *O. supinus* from the Avoca Limestone Member of the Lecompton Formation and the Ervine Creek Limestone of the Deer Creek Formation in the Shawnee Group of the Virgil Series, Cass County, Nebraska.

Vertigocrinus gloukosensis was originally described from the Haskell Limestone Member of the Cass Limestone in the Douglas Group of the Virgil Series, near Homewood, Kansas (Strimple 1951b, pp. 374–375). It has subsequently been reported from the Vinland Shale Member of the Plattford Formation in the Douglas Group of the Virgil Series (Strimple, 1971a, p. 199). Pabian and Strimple (1974a, pp. 283–284) reported this species from the Merriam Limestone Member of the Plattsburg Limestone in the Lansing Group of the Missouri Series, near Louisville, Nebraska, and also (1974b, pp. 30, 38) recorded it from the Coal Creek Limestone Member of the Topeka Limestone in the Shawnee Group of the Virgil Series, in Fremont County, Iowa, and the Curzon Limestone Member of the Topeka Limestone, Cass County, Nebraska. In 1980a (p. 18) Pabian and Strimple reported *V. gloukosensis* from the Plattsmouth Limestone Member of the Oread Formation; the Doniphan Shale and Beil Limestone Members of the Lecompton Formation; and the Ervine Creek Limestone Member of the Deer Creek Formation. All were in the Shawnee Group of the Virgil Series, in Montgomery County, Iowa, and Cass County, Nebraska.

Aglaocrinus compactus was described by Moore and Plummer (1940) from the Brad Formation in the Canyon Group of the Upper Pennsylvanian rocks near Pickwick, Texas, and from the Winterset Limestone Member of the Dennis Formation in the Kansas City Group of the Missouri Series. A comparable species also occurs in the Stull Shale Member of the Kanwaka Formation in the Shawnee Group of the Virgil Series in Cass County, Nebraska. Pabian and Strimple (1980a, p. 15) reported this species from the Beil Limestone Member of the Lecompton Formation and the Ervine Creek Limestone Member of the Deer Creek Formation, both in the Shawnee Group of the Virgil Series, from Montgomery County, Iowa, and Cass County, Nebraska.

Graffhamicrinus decapodos (Strimple and Priest, 1969) was described from the Kanwaka Formation in the Shawnee Group of the Virgil Series, Cass County, Nebraska. Recent fieldwork has shown that the source rock was the Stull Shale Member of the Kanwaka Formation, not the Snyderville Shale Member of the Oread Limestone in the Shawnee Group as was originally reported to have been the source. Pabian and Strimple (1980a, p. 5) reported this somewhat rare species from the Haskell Limestone Member of the Cass Formation in the Douglas Group of the Virgil Series, Cass County, Nebraska.

Several brachiopod species reported by Dunbar and Condra (1932) may aid in correlation of strata with the Stull Shale Member of the Kanwaka Formation. These include *Enteletes hemiplicatus* Hall, *Chonetes granulifer transversalis* Dunbar and Condra, *Derbyia ciscoensis* Dunbar and Condra, and *Wellerella osagensis* (Swallow), all of which first occur in the Oread Limestone, which immediately underlies the Kanwaka Formation. *Linoproductus carinatus* Dunbar and Condra is currently known only from the Kanwaka Formation in the Sedan, Kansas, area. Several other brachiopod species are known from the Oread Limestone or from the Oread and older rock units but not from younger rock units; these include: *Derbyia bennetti* Hall and Clarke, *D. kansasensis* Dunbar and Condra, *Chonetina flemingi alata* Dunbar and Condra, *Echinoconchus semipunctatus* (Shepard), *Leptolosia spondyliformis* White and St. John, *Poikilosakos petaloidea* Watson, *Wellerella osagensis immatura* Dunbar and Condra, *Rhynchopora illinoisensis* Worthen, and *Composita elongata* Dunbar and Condra. Of the above species, *D. bennetti* and *D. ciscoensis* occur in the Cisco Group (=Virgil Series) of Texas and *R. illinoisensis* occurs in the Carbondale Formation of the Kewanee Group of the Middle Pennsylvanian Series in Illinois.

BIOMETRICAL DATA

Univariate analysis.

Shaw (1957) proposed a standardized set of measurements for the dorsal shells of non-agnostidean trilobites. Because of the senior author's success in using such standardized measurements (see Pabian and Fagerstrom, 1968, 1972) Pabian and Strimple (1979) adopted a set of measurements for the flexible leacanocrinid, *Cibolocrinus conicus* Strimple. These measure-

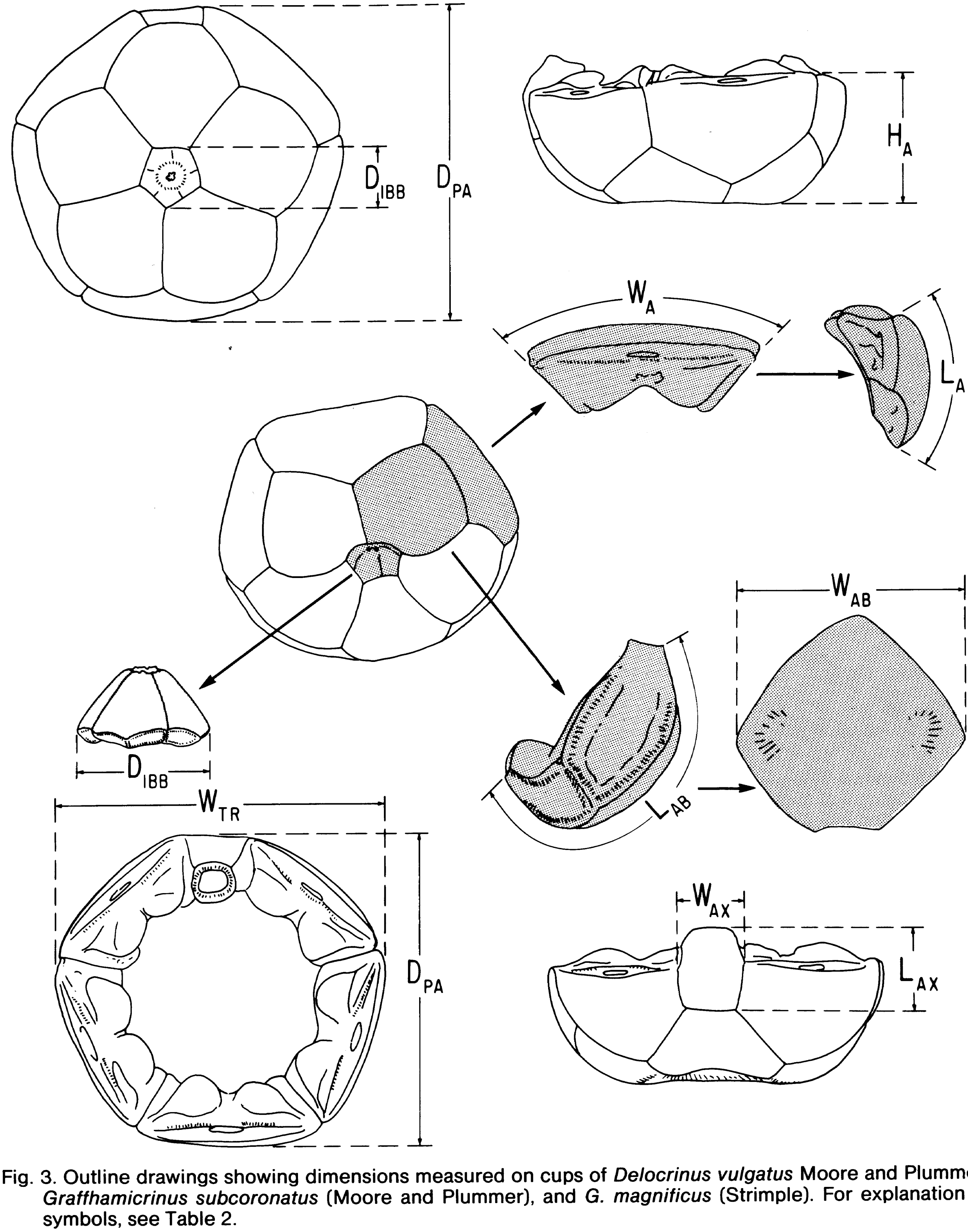

Fig. 3. Outline drawings showing dimensions measured on cups of *Delocrinus vulgatus* Moore and Plummer, *Graffhamicrinus subcoronatus* (Moore and Plummer), and *G. magnificus* (Strimple). For explanation of symbols, see Table 2.

TABLE 2
UNIVARIATE MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Delocrinus vulgatus* MOORE & PLUMMER FROM ACE HILL QUARRY (Location 1, Fig. 1).
[All measurements in mm. Measurements shown in Figure 2.]

DIMENSION	N	OBSERVED RANGE	MEAN	STANDARD DEVIATION
Diameter of Cup (Posterior-Anterior), D_{PA}	38	11.4–27.4	20.54	4.35
Width of Cup (Transverse), W_{TR}	42	12.2–29.0	21.53	4.49
Height of Cup (Anterior), H_A	40	4.7–9.8	7.58	1.55
Diameter of Infrabasal Circlet, D_{IBB}	42	2.1–5.6	3.90	0.79
Length of AB Basal, L_{AB}	40	5.4–15.1	10.48	2.57
Width of AB Basal, W_{AB}	42	6.8–15.9	10.73	2.23
Length of A Radial, L_A	41	4.2–9.9	7.32	1.48
Width of A Radial, W_A	41	6.8–17.6	12.65	2.62
Length of Anal X, L_{AX}	36	2.3–8.9	5.31	1.34
Width of Anal X, W_{AX}	37	1.4–5.5	3.41	1.21
Length of AB interradial suture, S^R_{AB}	39	2.0–5.4	3.93	0.86
Length of A interbasal suture, S^B_A	39	3.5–9.4	6.67	1.74

ments are readily adaptable to many of the cladid inadunate crinoids and are followed here.

Some of the more important univariate measures (see Fig. 3) which were computed from the sample are given in Tables 2, 3, 5, 6, 8, and 9. The observed ranges for diameter of dorsal cup (D_{PA}) indicates very small individuals of *Delocrinus vulgatus*, *Graffhamicrinus subcoronatus*, and *G. magnificus* to be missing. With the exception of a very tiny crown of *Moundocrinus* sp., no tiny crinoid cups were found. It is probable that the Stull Shale in Nebraska contains a winnowed fossil assemblage (*sensu* Fagerstrom, 1964) as few specimens of tiny brachiopods, bivalves, or snails were found. *Endelocrinus* has been used to include small delocrinids with dimples at plate junctions; *Tholiacrinus*, a synonym of *Graffhamicrinus*, was erected by Strimple (1961a) to include small graffhamicrinids with dimples at plate junctions. Since the original statistical work was completed, several small specimens of catacrinids and graffhamicrinids having dimples at plate junctions have been collected. These small specimens fit into the growth sequences shown in the scatter diagrams (Figs. 4–12) and are here included in either *Delocrinus vulgatus* or *Graffhamicrinus magnificus*.

Univariate analysis may be used with non-quantitative features (such as dimples at cup plate junctions) to some advantage. For example, our specimens show that these dimples become much smaller as cup diameter increases, and that dimples are essentially non-existent where cup diameter exceeds 12.0 mm.

TABLE 3
UNIVARIATE MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Delocrinus vulgatus* FROM WEEPING WATER (Location 2, Fig. 1)

DIMENSION	N	OBSERVED RANGE	MEAN	STANDARD DEVIATION
D_{PA}	25	13.3–27.4	21.88	3.64
W_{TR}	25	14.4–28.7	22.89	3.88
H_A	25	5.0–10.3	7.90	1.46
D_{IBB}	24	2.0–5.0	3.98	0.84
L_{AB}	22	6.5–13.9	10.66	1.95
W_{AB}	22	6.3–13.0	10.15	2.16
L_A	24	4.6–9.9	7.93	1.26
W_A	24	7.8–17.5	13.44	2.38
L_{AX}	22	4.1–8.8	6.23	1.27
W_{AX}	23	1.8 5.4	3.99	1.14
S_A^B	26	3.8–9.1	6.92	1.62
S_{AB}^R	26	2.0–5.4	4.04	0.79

The differences of means of samples of *Delocrinus vulgatus*, *Graffhamicrinus subcoronatus*, and *G. magnificus* from Ace Hill (Location 1) and Weeping Water (Location 2) were tested in the manner shown by Simpson, Roe, and Lewontin (1960, pp. 176–180). In all, three tests of six samples were made (Tables 4, 7, and 10). Most of the values obtained for t were, generally speaking, very low, suggesting that the samples of each of the above species from each of the localities were from the same population.

Delocrinus vulgatus (Tables 2–4).

Delocrinus vulgatus specimens from Weeping Water may have actually had slightly longer anal X plates (L_{AX}) than specimens from Ace Hill. The value of t (1.964, Table 4) indicates slightly better than 95 percent probability that the difference in means is significant for 57 degrees of freedom.

Graffhamicrinus subcoronatus (Tables 5–7).

Comparisons of means of diameter of cup from posterior to anterior (D_{PA}), anterior height of cup (H_A), and transverse width of cup (W_{TR}), show values for t of 1.551, 1.727, and 1.550 respectively. In all cases, the probability is greater than 90 percent that the differences in means is significant and that *Graffhamicrinus subcoronatus* from Weeping Water actually is a bit larger than *G. subcoronatus* at Ace Hill. The anal X plates on specimens from Weeping Water are also slightly wider (W_{AX}) than on specimens from Ace Hill (t = 1.951; Table 7).

Graffhamicrinus magnificus (Tables 8–10).

Specimens of *Graffhamicrinus magnificus* from Ace Hill also may have had longer anal X plates (L_{AX}) than specimens from Weeping Water as indicated by the high value of t, 4.237, for 18

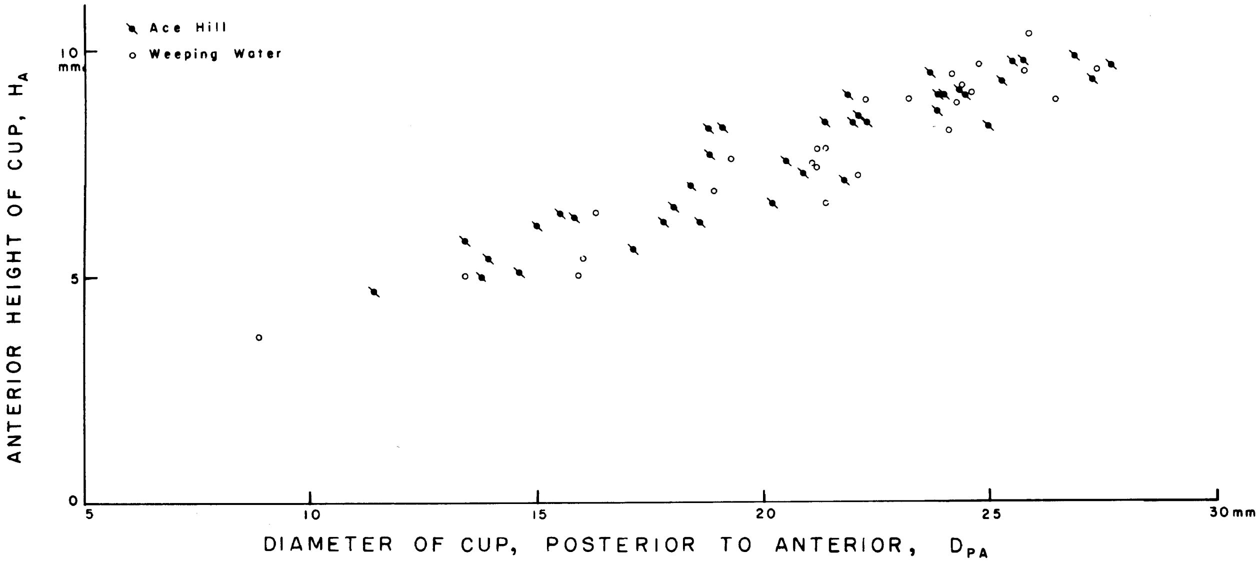

Fig. 4. Scatter diagram for paired cup dimensions H_A and D_{PA} for *Delocrinus vulgatus* from Ace Hill and Weeping Water, Nebraska.

TABLE 4
COMPARISONS OF MEANS OF MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Delocrinus vulgatus* FROM ACE HILL AND WEEPING WATER

DIMENSION	D.F.	t
D_{PA}	61	1.273
W_{TR}	65	1.248
H_A	63	0.536
D_{IBB}	64	0.386
L_{AB}	60	0.285
W_{AB}	62	0.999
L_A	63	1.691
W_A	63	0.478
L_{AX}	57	1.964
W_{AX}	58	1.560
S^R_{AB}	63	0.440
S^B_A	63	0.559

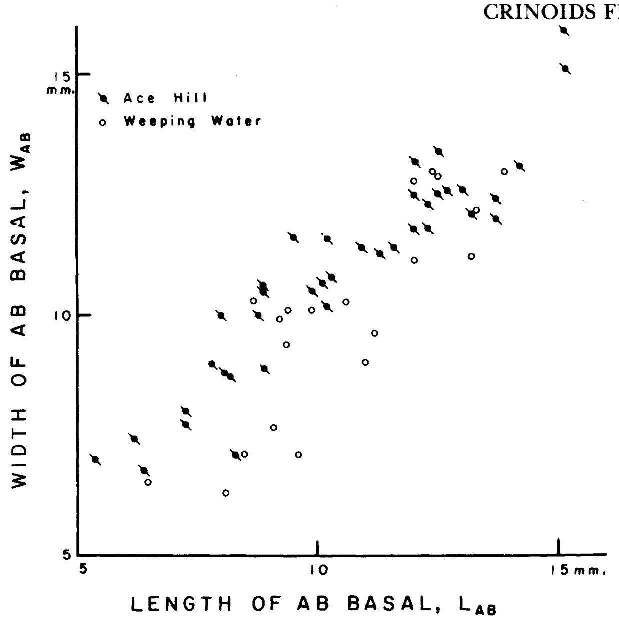

Fig. 5. Scatter diagram for paired cup dimensions W_{AB} and L_{AB} for *Delocrinus vulgatus* from Ace Hill and Weeping Water, Nebraska.

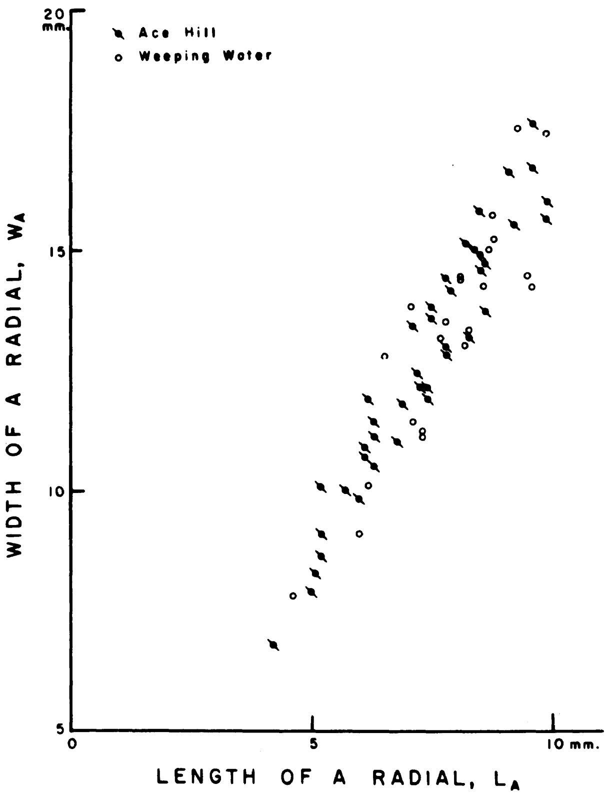

Fig. 6. Scatter diagram for paired cup dimensions W_A and L_A for *Delocrinus vulgatus* from Ace Hill and Weeping Water, Nebraska.

TABLE 5
UNIVARIATE MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Graffhamicrinus subcoronatus* (MOORE & PLUMMER) FROM ACE HILL (Location 1, Fig. 1)

DIMENSION	N	OBSERVED RANGE	MEAN	STANDARD DEVIATION
D_{PA}	31	12.7–29.3	19.66	4.03
W_{TR}	33	13.4–30.7	20.51	4.01
H_A	33	5.2–10.5	7.55	1.43
D_{IBB}	33	2.4–5.8	3.76	0.79
L_{AB}	34	6.1–17.0	10.11	2.42
W_{AB}	34	7.0–15.5	11.25	2.29
L_A	33	4.3–10.5	6.81	1.53
W_A	33	8.0–18.7	12.04	2.56
L_{AX}	30	3.4–8.1	5.12	1.34
W_{AX}	30	1.5–5.5	3.08	0.92
S_A^B	35	3.6–9.3	6.33	1.44
S_{AB}^R	35	2.1–5.1	3.48	0.75

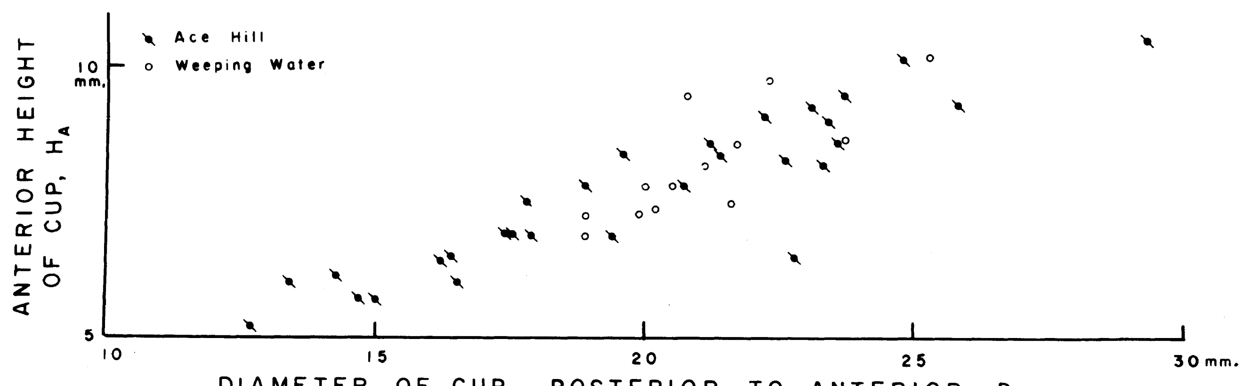

Fig. 7. Scatter diagram for paired cup dimensions H_A and D_{PA} for *Graffhamicrinus subcoronatus* from Ace Hill and Weeping Water, Nebraska.

TABLE 6
UNIVARIATE MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Graffhamicrinus subcoronatus* FROM WEEPING WATER (Location 2, Fig. 1)

DIMENSION	N	OBSERVED RANGE	MEAN	STANDARD DEVIATION
D_{PA}	14	18.9–25.3	21.43	2.02
W_{TR}	14	19.9–26.5	22.47	2.00
H_A	13	6.9–10.2	8.22	1.04
D_{IBB}	13	3.0–4.3	3.66	0.49
L_{AB}	13	9.5–12.0	10.74	0.83
W_{AB}	13	9.3–12.5	11.60	1.16
L_A	13	5.2–9.1	7.41	1.10
W_A	13	10.6–15.8	12.89	1.40
L_{AX}	12	3.9–7.3	5.63	0.97
W_{AX}	12	2.6–4.7	3.60	0.78
S_A^B	13	5.6–7.8	6.84	0.73
S_{AB}^R	13	2.3–4.6	3.54	0.70

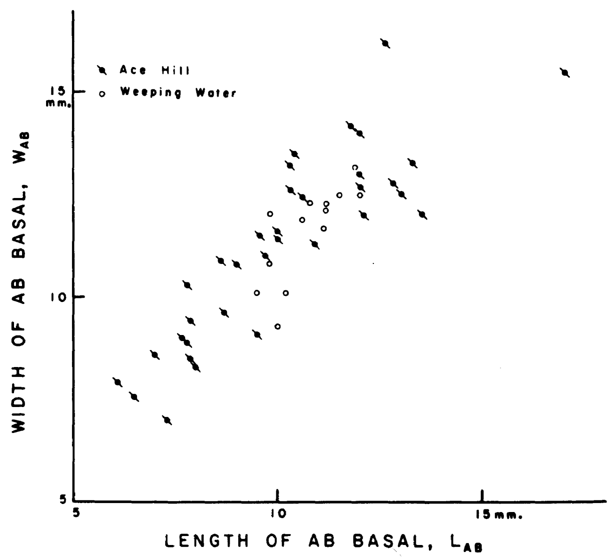

Fig. 8. Scatter diagram for paired cup dimensions W_{AB} and L_{AB} for *Graffhamicrinus subcoronatus* from Ace Hill and Weeping Water, Nebraska.

TABLE 7
COMPARISONS OF MEANS OF MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Graffhamicrinus subcoronatus* FROM ACE HILL AND WEEPING WATER

DIMENSION	D.F.	t
D_{PA}	43	1.551
W_{TR}	46	1.727
H_A	45	1.550
D_{IBB}	44	0.485
L_{AB}	45	0.431
W_{AB}	45	0.255
L_A	44	0.901
W_A	44	0.489
L_{AX}	40	1.195
W_{AX}	40	1.951
S^B_A	46	1.214
S^R_{AB}	46	0.250

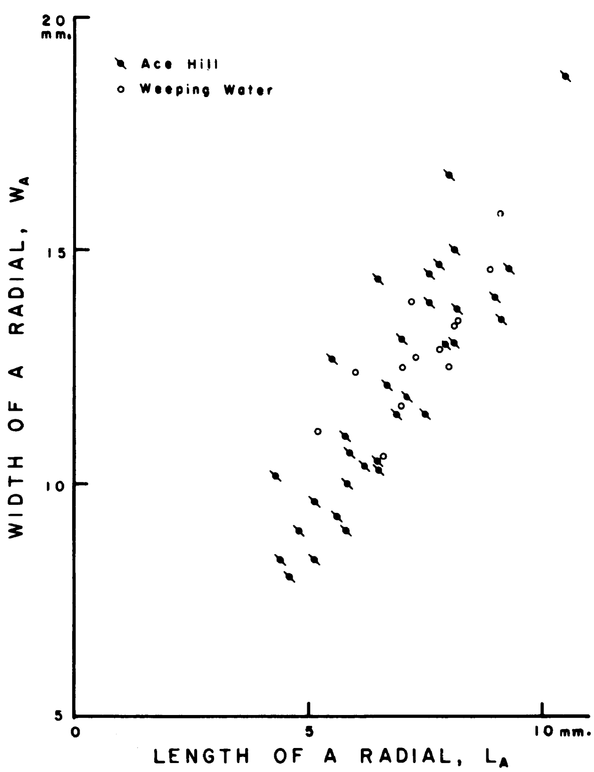

Fig. 9. Scatter diagram for paired cup dimensions W_A and L_A for *Graffhamicrinus subcoronatus* from Ace Hill and Weeping Water, Nebraska.

TABLE 8
UNIVARIATE MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Graffhamicrinus magnificus* (STRIMPLE) FROM ACE HILL (Location 1, Fig. 1)

DIMENSION	N	OBSERVED RANGE	MEAN	STANDARD DEVIATION
D_{PA}	7	21.8–25.9	23.22	1.71
W_{TR}	7	22.3–27.9	24.31	2.19
H_A	7	7.7–10.0	8.53	1.06
D_{IBB}	7	3.1–5.0	3.98	0.61
L_{AB}	7	10.7–16.2	12.61	1.88
W_{AB}	7	8.0–13.0	11.49	1.64
L_A	7	6.9–10.0	8.30	1.10
W_A	7	13.1–16.3	14.5	1.28
L_{AX}	6	5.5–7.7	7.57	0.86
W_{AX}	6	1.9–4.5	3.37	1.16
S^R_{AB}	7	5.6–8.6	7.30	1.12
S^B_A	7	3.7–5.0	4.30	0.49

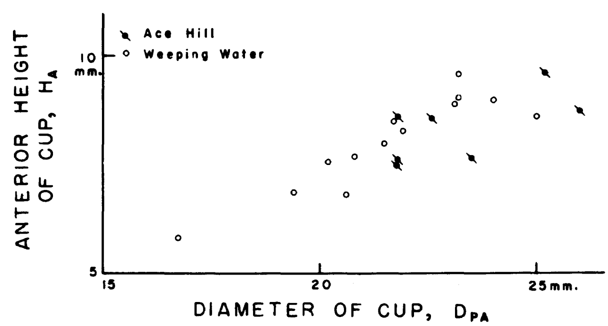

Fig. 10. Scatter diagram for paired cup dimensions H_A and D_{PA} for *Graffhamicrinus magnificus* from Ace Hill and Weeping Water, Nebraska.

TABLE 9
UNIVARIATE MEASUREMENTS COMPUTED FROM DORSAL CUPS AND PLATES OF *Graffhamicrinus magnificus* FROM WEEPING WATER (Location 2, Fig. 1)

DIMENSION	N	OBSERVED RANGE	MEAN	STANDARD DEVIATION
D_{PA}	13	16.7–25.0	21.64	2.18
W_{TR}	13	17.8–25.1	22.61	2.16
H_A	13	5.8–9.6	8.06	1.08
D_{IBB}	11	3.1–4.0	3.56	0.36
L_{AB}	12	7.9–13.8	11.02	1.67
W_{AB}	12	8.3–13.0	11.32	1.48
L_A	12	6.4–10.0	8.11	1.06
W_A	13	10.3–16.2	13.83	1.76
L_{AX}	11	4.1–6.9	5.72	0.86
W_{AX}	11	1.5–4.3	2.81	0.84
S^B_{AB}	12	4.0–9.0	6.68	1.23
S^B_A	12	2.8–4.8	4.07	0.66

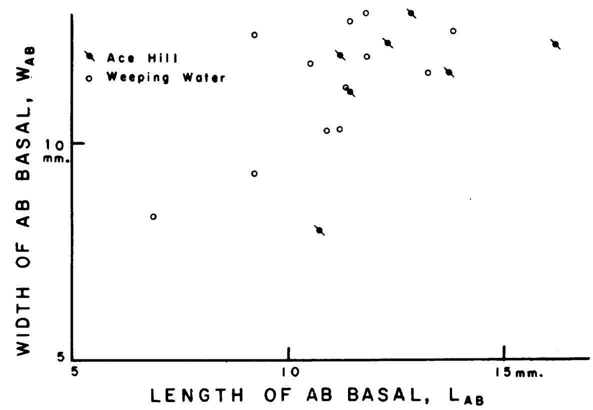

Fig. 11. Scatter diagram for paired cup dimensions W_{AB} and L_{AB} for *Graffhamicrinus magnificus* from Ace Hill and Weeping Water, Nebraska.

TABLE 10
COMPARISONS OF MEANS OF UNIVARIATE MEASUREMENTS OF *Graffhamicrinus magnificus* FROM ACE HILL AND WEEPING WATER

DIMENSION	D.F.	t
D_{PA}	18	1.656
W_{TR}	18	1.671
H_A	18	0.934
D_{IBB}	16	1.852
L_{AB}	17	1.913
W_{AB}	17	0.232
L_A	17	0.256
W_A	18	0.884
L_{AX}	15	4.237
W_{AX}	15	1.151
S^R_{AB}	17	1.093
S^B_A	17	0.797

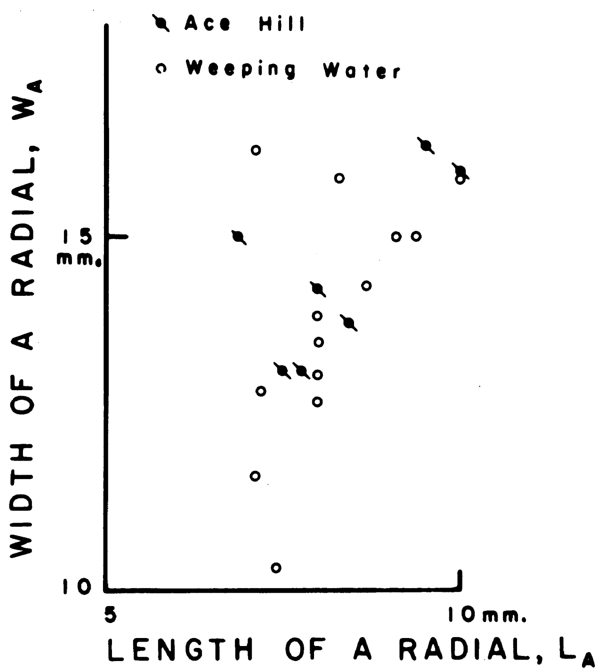

Fig. 12. Scatter diagram for paired cup dimensions W_A and L_A for *Graffhamicrinus magnificus* from Ace Hill and Weeping Water, Nebraska.

degrees of freedom (Table 10). The cups of *G. magnificus* from Ace Hill may also have been slightly larger than those from Weeping Water, as indicated by values of t for D_{PA} (1.656) and W_{TR} (1.671) for 18 degrees of freedom. (See Table 10.)

The above differences are minor and are thought to reflect only local changes in environments of deposition between Weeping Water and Ace Hill.

Bivariate analysis.

Bivariate data for *Delocrinus vulgatus* Moore and Plummer, *Graffhamicrinus subcoronatus* (Moore and Plummer), and *G. magnificus* (Strimple) provided some interesting observations on three morphologically similar, but not necessarily closely related, crinoid species. The use of univariate analysis in paleontology is limited as an interpretive tool in taxonomy since it gives no information concerning morphological changes during growth. The present study of the three species listed is based largely upon bivariate measures for paired dimensions as indicated in Figure 3 and Tables 11–19. The choice of paired dimensions for bivariate analysis is based largely upon previous work of Pabian and Strimple (1974b, pp. 41–48, Tables 2, 3; Fig. 20).

Scatter diagrams were prepared for each pair

TABLE 11
BIVARIATE MEASUREMENTS COMPUTED FROM CUPS AND PLATES OF *Delocrinus vulgatus* MOORE & PLUMMER FROM ACE HILL
(Location 1, Fig. 1) [R=Total correlation coefficient. Symbols for paired dimensions as in Table 2 and Fig. 2.]

PAIRED DIMENSION (Y,X)	N	R	REDUCED MAJOR AXIS EQUATION
H_A, D_{PA}	36	.938	$H_A = .332\ D_{PA} + .819$
D_{IBB}, D_{PA}	36	.794	$D_{IBB} = .141\ D_{PA} + .973$
W_{TR}, D_{PA}	38	.992	$W_{TR} = 1.016\ D_{PA} + .747$
W_{AB}, L_{AB}	40	.936	$W_{AB} = .813\ L_{AB} + 2.302$
L_A, L_{AB}	39	.917	$L_A = .523\ L_{AB} + 1.875$
W_A, W_{AB}	41	.921	$W_A = 1.071\ W_{AB} + 1.114$
W_A, L_A	42	.926	$W_A = 1.429\ L_A + 2.275$
W_{AX}, L_{AX}	36	.789	$W_{AX} = .629\ L_{AX} - .074$
S^R_{AB}, S^B_A	39	.846	S^R_{AB}, $= .419\ S^B_A + 1.127$

TABLE 12
BIVARIATE MEASUREMENTS COMPUTED FROM CUPS AND PLATES OF *Delocrinus vulgatus* MOORE & PLUMMER FROM WEEPING WATER
[Location 2, Fig. 1]

PAIRED DIMENSION (Y,X)	N	R	REDUCED MAJOR AXIS EQUATION
H_A, D_{PA}	24	.919	$H_A = .368\ D_{PA} - .157$
D_{IBB}, D_{PA}	24	.815	$D_{IBB} = .184\ D_{PA} - .057$
W_{TR}, D_{PA}	25	.986	$W_{TR} = 1.051\ D_{PA} - .123$
W_{AB}, L_{AB}	22	.950	$W_{AB} = .950\ L_{AB} + .007$
L_A, L_{AB}	22	.862	$L_A = .579\ L_{AB} + 1.778$
W_A, W_{AB}	22	.759	$W_A = .859\ W_{AB} + 4.814$
W_A, L_A	24	.897	$W_A = 1.695\ L_A + .003$
W_{AX}, L_{AX}	22	.800	$W_{AX} = .711\ L_{AX} - .495$
S^R_{AB}, S^B_A	26	.830	$S^R_{AB} = .404\ S^B_A + 1.239$

of dimensions listed in Tables 11–19 and in all cases the general trends of points were rectilinear (Figs. 4–12). Therefore, the dominant growth pattern for each selected pair of measurements made for individual plates, adjacent plates, or entire cups was isometric. Isometric patterns indicate that the dimensions being compared were increasing at the same relative rate, even though their absolute values may have been considerably different. More precisely, bivariate analysis can present a great deal of information on morphological changes during growth over the entire observed range of a sample of fossils.

Ratios between variates.

The use of the ratio between two dimensions has been a common, although flawed, practice in taxonomy for many years. Evidence from this study indicates that many ratios may be highly unsatisfactory taxonomic criteria. Shaw (1956, pp. 1212, 1213) indicated that a ratio has three distinct flaws: (1) it is a secondary statistic that is the quotient of two observations, each of which has its own variance; (2) any departure of the regression of the two variates from strict rectilinearity will cause statistically significant differences to appear where there are none in the original data; (3) ratios are generally not applicable to more than one growth stage at a time.

TABLE 13
COMPARISONS OF COEFFICIENTS OF REGRESSION FOR BIVARIATE MEASUREMENTS ON *Delocrinus vulgatus* MOORE & PLUMMER FROM ACE HILL AND WEEPING WATER. VALUE OF t (Student's t) COMPUTED FROM METHODS GIVEN BY SHAW (1956, pp. 1218–1220)

COMPARED COEFFICIENT (*Y,X*)	σ_{d_b}	t	D.F.
H_A, D_{PA}	.036	1.000	56
D_{IBB}, D_{PA}	.037	1.162	56
W_{TR}, D_{PA}	.045	0.777	59
W_{AB}, L_{AB}	.098	1.397	58
L_A, L_{AB}	.079	0.708	57
W_A, W_{AB}	.156	1.358	59
W_A, L_A	.201	1.323	62
W_{AX}, L_{AX}	.155	1.045	54
S^R_{AB}, S^B_A	.069	0.217	61

TABLE 14
BIVARIATE MEASUREMENTS COMPUTED FROM CUPS AND PLATES OF *Graffhamicrinus subcoronatus* (MOORE & PLUMMER) FROM ACE HILL (Location 1, Fig. 1).
[R = Total correlation coefficient. Symbols for paired dimensions as in Table 2 and Fig. 2.]

PAIRED DIMENSION (*Y,X*)	N	R	REDUCED MAJOR AXIS EQUATION
H_A, D_{PA}	31	.915	$H_A = .332\ D_{PA} + 1.183$
D_{IBB}, D_{PA}	31	.858	$D_{IBB} = .169\ D_{PA} + .382$
W_{TR}, D_{PA}	31	.987	$W_{TR} = .982\ D_{PA} + .983$
W_{AB}, L_{AB}	34	.866	$W_{AB} = .822\ L_{AB} + 2.293$
L_A, L_{AB}	33	.893	$L_A = .575\ L_{AB} + 1.053$
W_A, W_{AB}	33	.742	$W_A = .936\ W_{AB} + 1.226$
W_A, L_A	33	.864	$W_A = 1.439\ L_A + 2.237$
W_{AX}, L_{AX}	30	.824	$W_{AX} = .572\ L_{AX} + .152$
S^R_{AB}, S^B_A	35	.838	$S^R_{AB} = .431\ S^B_A + .689$

TABLE 15
BIVARIATE MEASUREMENTS COMPUTED FROM CUPS AND PLATES OF *Graffhamicrinus subcoronatus* (MOORE & PLUMMER) FROM WEEPING WATER (Location 2, Fig. 1.
[R = Total correlation coefficient. Symbols for paired dimensions as in Table 2 and Fig. 2.]

PAIRED DIMENSION (*Y,X*)	N	R	REDUCED MAJOR AXIS EQUATION
H_A, D_{PA}	13	.799	$H_A = .457\ D_{PA} - 1.451$
D_{IBB}, D_{PA}	13	.720	$D_{IBB} = .195\ D_{PA} - .478$
W_{TR}, D_{PA}	14	.972	$W_{TR} = .964\ D_{PA} + 1.801$
W_{AB}, L_{AB}	13	.782	$W_{AB} = 1.094\ L_{AB} - .155$
L_A, L_{AB}	13	.620	$L_A = .825\ L_{AB} - 1.454$
W_A, W_{AB}	13	.695	$W_A = .695\ W_{AB} + 3.062$
W_A, L_A	13	.811	$W_A = 1.029\ L_A + 5.256$
W_{AX}, L_{AX}	12	.395	$W_{AX} = .316\ L_{AX} + 1.816$
S^R_{AB}, S^B_A	13	.630	$S^R_{AB} = .607\ S^B_A - .633$

TABLE 16
COMPARISON OF COEFFICIENTS OF REGRESSION FOR BIVARIATE MEASUREMENTS OF *Graffhamicrinus subcoronatus* (MOORE & PLUMMER) FROM ACE HILL AND WEEPING WATER. VALUE OF *t* (Student's *t*) COMPUTED FROM METHODS GIVEN BY SHAW (1956, pp. 1218–1220)

COMPARED COEFFICIENT (*Y,X*)	σ_{d_b}	t	D.F.
H_A, D_{PA}	.089	1.404	40
D_{IBB}, D_{PA}	.100	2.600	40
W_{TR}, D_{PA}	.078	0.192	41
W_{AB}, L_{AB}	.373	0.729	43
L_A, L_{AB}	.098	2.550	42
W_A, W_{AB}	.405	0.595	42
W_A, L_A	.339	1.209	42
W_{AX}, L_{AX}	.199	1.286	38
S^R_{AB}, S^B_A	.335	0.525	44

TABLE 17
BIVARIATE MEASUREMENTS COMPUTED FROM CUPS AND PLATES OF *Graffhamicrinus magnificus* (STRIMPLE) FROM ACE HILL (Location 1, Fig. 1).
[R = Total correlation coefficient. Symbols for paired dimensions as in Table 2 and Fig. 2.]

PAIRED DIMENSION (Y,X)	N	R	REDUCED MAJOR AXIS EQUATION
H_A, D_{PA}	7	.307	$H_A = .189\ D_{PA} + 4.131$
D_{IBB}, D_{PA}	7	.422	$D_{IBB} = .159\ D_{PA} + .278$
W_{TR}, D_{PA}	7	.949	$W_{TR} = 1.212\ D_{PA} - 3.837$
W_{AB}, L_{AB}	7	.505	$W_{AB} = .439\ L_{AB} + 5.944$
L_A, L_{AB}	7	.842	$L_A = .492\ L_{AB} + 2.090$
W_A, W_{AB}	7	.272	$W_A = 2.13\ W_{AB} + 12.050$
W_A, L_A	7	.665	$W_A = .776\ L_A + 8.058$
W_{AX}, L_{AX}	6	.253	$W_{AX} = .322\ L_{AX} + 1.248$
S^R_{AB}, S^B_A	7	.187	$S^R_{AB} = .083\ S^B_A + 3.695$

TABLE 18
BIVARIATE MEASUREMENTS COMPUTED FROM CUPS AND PLATES OF *Graffhamicrinus magnificus* (STRIMPLE) FROM WEEPING WATER (Location 2, Fig. 1).
[R = Total correlation coefficient. Symbols for paired dimensions as in Table 2 and Fig. 2.]

PAIRED DIMENSION (Y,X)	N	R	REDUCED MAJOR AXIS EQUATION
H_A, D_{PA}	13	.899	$H_A = .444\ D_{PA} - 1.549$
D_{IBB}, D_{PA}	11	.588	$D_{IBB} = .097\ D_{PA} + 1.484$
W_{TR}, D_{PA}	12	.963	$W_{TR} = .955\ D_{PA} + 1.943$
W_{AB}, L_{AB}	12	.634	$W_{AB} = .562\ L_{AB} + 5.121$
L_A, L_{AB}	12	.628	$L_A = .331\ L_{AB} + 4.286$
W_A, W_{AB}	12	.795	$W_A = .923\ W_{AB} + 3.209$
W_A, L_A	13	.659	$W_A = 1.134\ L_A + 4.635$
W_{AX}, L_{AX}	11	.627	$W_{AX} = .608\ L_{AX} - .668$
S^B_A, S^R_{AB}	12	.671	$S^B_A = .387\ S^R_{AB} + 1.481$

The use of ratios in crinoid taxonomy should therefore be carefully reviewed.

The standard form for an equation in two unknowns (X and Y) is given by:

1. $Y = bX + a.$

The equations for regressions in Tables 11, 12, 14, 15, 17, and 18 are given in this same form: X and Y in equation 1 are two different dimensions of the dorsal cup; b is the growth rate, or slope of the growth line; and a is the initial growth index, or the value of Y when X equals zero.

The relations between these same four variables may be expressed in the form

2. $(Y - a)/X = b$

Then, as the absolute value of a $|a|$ approaches zero, the ratio Y/X approximates b and is relatively constant regardless of the values of Y, X, and b. The greater the difference between $|a|$ and zero, the greater the difference between the ratio Y/X and b. Thus, if the values of a and b remain constant, the value of the ratio Y/X depends upon the absolute values of Y and X and is not constant.

These mathematical concepts were expressed in terms of biological significance by Pabian and Fagerstrom (1968, pp. 201–202) as follows:

1. If growth is isometric, the greater the difference in the absolute value of the initial growth index $|a|$ and zero, the more the value in the ratio Y/X will vary during growth.

TABLE 19
COMPARISONS OF COEFFICIENTS OF REGRESSION OF BIVARIATE MEASURES OF *Grafthamicrinus magnificus* FROM ACE HILL AND WEEPING WATER

PAIRED DIMENSIONS	D.F.	t
H_A, D_{PA}	16	0.685
D_{IBB}, D_{PA}	14	0.512
W_{TR}, D_{PA}	15	1.452
W_{AB}, L_{AB}	15	0.401
L_A, L_{AB}	15	0.851
W_A, W_{AB}	15	1.854
W_A, L_A	16	0.615
W_{AX}, L_{AX}	12	0.487
S_A^B, S_{AB}^R	15	1.357

2. The greater the variation in the value of the ratio Y/X, the less suitable it is as a taxonomic criterion (Shaw, 1956, pp. 1212–1213).

3. The greatest variation in the value of the ratio occurs when the dimensions (Y and X) are small. Thus, the ratio between two dimensions may change considerably during early ontogenetic stages and have only limited significance, whereas the ratio between the same two dimensions may be relatively constant during later ontogeny and, therefore, become a useful taxonomic criterion.

Examination of the data in Tables 11, 12, 14, 15, 17, and 18 will reveal the absolute of a, $|a|$, and the regressions which should serve as suitable taxonomic criteria. A new problem is encountered, however. In samples of *Delocrinus vulgatus*, for example, the regression comparing the width of the A radial, W_A, to the length of the A radial, L_A, from Ace Hill is given by

$$W_A = 1.429L_A + 2.275,$$

and from Weeping Water by

$$W_A = 1.695L_A + 0.003.$$

The W_A:L_A is relatively constant for the sample from Weeping Water but is highly variable in the sample from Ace Hill. In other words, the ratio may not hold as a good test even on a sample-to-sample basis. The same observations can be made for many of the paired dimensions given in Tables 11, 12, 14, 15, 17, 18. If these observations are substantiated by more extensive studies, the practice of considering ratios as valid taxonomic criteria even at the specific level should be discontinued.

Comparisons of Samples

Bivariate analysis was a very useful tool for testing the difference between separate samples of *Delocrinus vulgatus*, *Grafthamicrinus subcoronatus*, and *G. magnificus*. Shaw (1956, pp. 1218–1220) provided a relatively simple method of comparing coefficients of regression of samples of two different species. We have utilized Shaw's method to test the differences of coefficients of regression of samples of *Delocrinus vulgatus*, *Grafthamicrinus subcoronatus*, and *G. magnificus* from Weeping Water and Ace Hill, two locations separated by about 15 miles. This is done by calculating student's t from the quotient of the differences in the observed coefficients and the computed standard error of difference between the coefficients of regression. That is, a value for t can be derived to test to see if coefficients of regression for the same pairs of variates are different or similar for two species, or, as in our case, two different samples of three different species. In the six samples compared, the standard errors of coefficients of regression (s_{DB}) were calculated by the method given by Shaw (1956, p. 1218). From these standard errors, t was derived. In most cases the value of t (Tables 13, 16, and 19) was low, indicating that there were no statistical differences in the slopes of the lines of the samples compared.

Scatter diagrams

The most interesting discovery made while plotting data was that cup measurements on three different and not closely related species show essentially identical scatter diagram point distributions and have similar reduced major axis regressions. However, this should have been expected. The three species that were biometrically analyzed all showed the following common characteristics: (1) all have low to medium bowl-shaped cups with moderately deep basal invaginations; (2) all have three circlets of plates, the infrabasal, basal, and radial; (3) the infrabasal circlet is confined to the basal concavity; (4) the proximal third of the basal circlet is confined to the basal concavity, the medial third forms the basal plane of the cup, and the distal third is confined entirely to the wall of the cup above the basal plane; (5) the radial circlet is confined entirely to the wall of the cup and an anal X plate is inserted between the C and D radii; (6) a smooth line connecting the widest areas of the plates in any ray (or interray) defines a circle; (7) each plate occupies 72 degrees of arc in the infrabasal and basal circlets and slightly less in the radial circlet because of the anal X plate. The principal differences in the three species are shown in Table 20.

There is no gradation in the nature of cup ornamentation shown by the three species. The cups will all either be smooth (*Delocrinus vulgatus*), evenly roughened (*Graffhamicrinus subcoronatus*), or coarsely ornamented with oriented ridges, nodes, and tubercles (*G. magnificus*). In *G. subcoronatus* the roughened surface is irregular and pitted, whereas the fine nodes on *G. magnificus* are evenly spaced and evenly raised above the cup surface.

Delocrinus vulgatus and *G. magnificus* have only slightly protruded first primibrachials. *G. subcoronatus* has spinose first primibrachials. The arms of *D. vulgatus* rise evenly and crowns have a cylindrical cross section, whereas the arms of *G. magnificus* and *G. subcoronatus* expand above the cup summit and taper sharply near the apex, giving the crown a pyriform cross section.

The fact that *Graffhamicrinus magnificus* shows a strong tendency to expel or resorb the anal X

TABLE 20
MORPHOLOGICAL DIFFERENCES IN THE CRINOID SPECIES *Delocrinus vulgatus* MOORE & PLUMMER, *Graffhamicrinus subcoronatus* (MOORE & PLUMMER) AND *G. magnifus* (STRIMPLE) FROM ACE HILL AND WEEPING WATER

CHARACTER	SPECIES *D. vulgatus*	*G. subcoronatus*	*G. magnificus*
Crown profile	Cylindrical	Cylindrical	Pyriform
Primibrachials	Slightly protruded	Spinose	Slightly protruded
Ornamentation*	None, cup and arms usually smooth (see systematics).	Roughened surface, not extending to arms.	Numerous coarse nodes and pustules, large ridges, extending onto arms.
Arms	Taper distally.	Taper distally.	Expand medially and taper distally.
Anal plate	Erect, broad.	Erect, narrow.	Leans inward; tends to be expelled.

* There is no gradation in nature or degree of ornamentation.

plate is very important. This important evolutionary trend is not present in the samples of *D. vulgatus* or *G. subcoronatus, and it is clear that G. magnificus* followed an evolutionary trend totally different from the other two species.

The similar scatter diagrams and regressions for the above three crinoid species possibly have greater ecological than biometrical significance. In any environment, the most successful species will probably have the greatest number of characteristics that enable them to survive and flourish. These two genera are the most abundant crinoids in the Stull Shale. They display sufficient different characteristics to designate each to a separate species, but they also display sufficient common characteristics to demonstrate that they were able to adapt and to propagate in great numbers.

Morphologically similar crinoid cups of not even remotely related species, therefore, should be expected to show similar, if not identical, scatter diagram point distributions and reduced major axis equations (Figs. 4–12). This is because crinoid growth takes place in a closed system in which all growth events are confined to a geometric solid that has a circular, plane-cross section, such as a cone, cylinder, ellipsoid, or torus.

The same argument of scatter diagram distributions does not necessarily apply to any other group of invertebrates because they grow in an open system. For example, a trilobite may grow peripherally in a plane that is defined by 360 degrees of arc; however, the circular plane cross section as given above is not a geometrically imposed restriction as in crinoids.

The above suggests inherent dangers in making synonyms of various crinoid species because their plotted measurements produce similar scatter diagrams, reduced major axis regressions, means, or standard deviations. Strong arguments for retaining the three separate species in the present example can also be made by observing qualitative data, such as cup plate ornamentation, cup plate tumidity, or the nature of the sutures between cup plates, and evolutionary tendencies.

CUP PLATE GROWTH

It is difficult to carry out a detailed biometric study of crinoids without speculating on the modes of cup plate growth. Sprinkle (1971, p. 44) has done detailed work on blastoid plate growth increments but less has been done with crinoids. Furthermore, there has been but little work directed towards the interactions between adjacent plates as modes of growth change. Crinoid plate growth takes place in a closed system as previously pointed out. Echinoderm growth may be accomplished by the addition of stereom to pre-existing plates, or by the addition of new plates to the skeleton (Sprinkle, 1971, p. 44). All species studied here show the former mode of growth over the observed size ranges.

The geometric restrictions imposed by the circle provide some hypothetical examples of cup morphology as related to individual plate morphology, and some of these are discussed in the following paragraphs.

(1) From the initial directional control (a flat, concave, or convex base) the infrabasal circlet may be deepened or shallowed by the subtraction or addition of stereom on the interradial sutures (Fig. 13). The infrabasal circlet must remain confined to 360 degrees of arc. Thus, if the infrabasals are kite-shaped (Fig. 13a), the entire infrabasal circlet will approximate a deep paraboloid structure. The addition of new stereom to the interradial sutures (Fig. 13c) will result in a low, spheroid or umbrella-like infrabasal circlet (Fig. 13e). Resorption of material along the interradial sutures (Fig. 13b) will deepen the paraboloid (Fig. 13d). Likewise, any combination of proximal or distal addition or resorption of material along interradial sutures can alter the nature of the infrabasal circlet.

(2) Plates of the other two circlets will respond to the addition or resorption of stereom from the interradial sutures of the infrabasal circlet. If the growth increments are added to the infrabasals in pie-slice increments (Figs. 14c,d); there will be little if any change in cup shape during ontogeny: radial and interradial growth increments will be added in these radially arranged, pie-slice increments. In addition to radial and interradial growth increments, circumferential growth increments will be added along the sutures between adjacent infrabasals, basals, and radials. This will add to the total radial length of the cup walls, which is defined here as the sum of the lengths of the

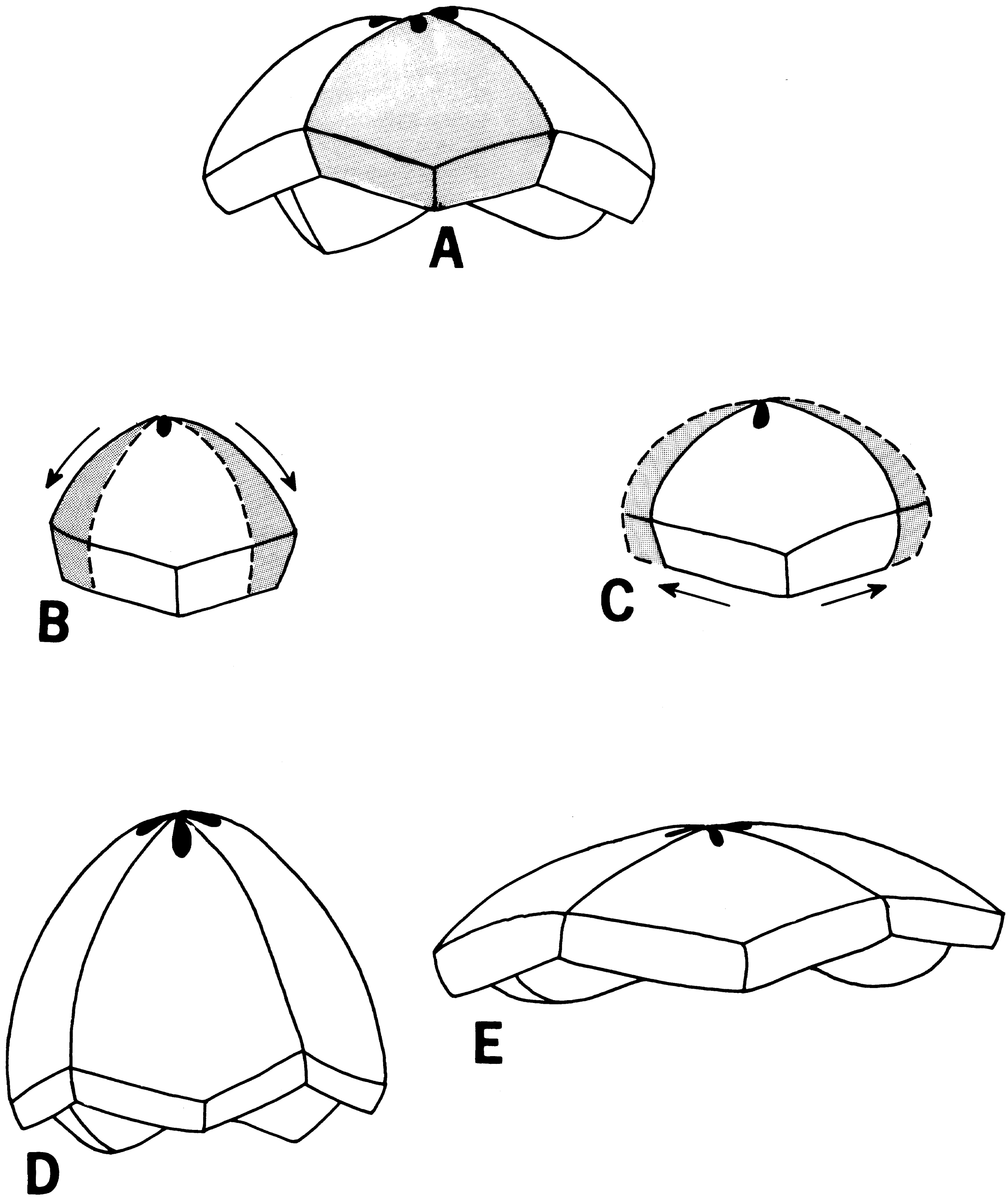

Fig. 13. Changes in infrabasal circlet and basal concavity of dorsal cup caused by changes of growth increments of individual infrabasal plates. Arrows point in direction of most rapid growth.

infrabasal plate, the interbasal suture, and the length of a radial plate as measured along a given ray.

(3) Growth increments added evenly around all of the plates may account for radical changes in cup shape during the ontogeny of the animal (Fig. 14a). For example, assume a basal plate of a small crinoid is 1 mm long and 2 mm wide. If equal peripheral growth increments of 1 mm total are added to the plate at each growth cycle, the plate will measure 2 x 3 mm at the end of cycle 1, (C/1), 3 x 4 (C/2), 4 x 5 (C/3), 5 x 6 (C/4), 6 x 7 (C/5), ... 51 x 52 (C/50), n x n + 1, (C/N). In other words, the length/width ratio of the basal plate, or any plate, changes from 1:2 (C/1), 3:4 (C/2), 5:6 (C/3), to nearly 1:1 (C/N). Not only does this argument have ontogenetic significance but also phyletic significance. Assume that growth increments are equally added to the periphery of the basal plate. Then, in any individual crinoid the plates will change shape in the fashion just described, from C/1 to C/N. If a crinoid in a lineage of crinoids of which the individual crinoid is a descendant/ancestor grows by adding material nearer the basal-infrabasal suture at a relatively faster rate (Fig. 14b) than the basal-radial suture area, evolution will proceed toward crinoids having cups with broad, shallow bases. The mode of growth shown by an individual crinoid or even a large population of individuals sampled from the same time plane (Figs. 14a, b) may appear considerably different from the evolutionary trend of the lineage of which the crinoid is a member.

(4) Conversely, if growth increments of the basals are added nearer to the distal ends of the radially situated sutures at a relatively faster rate, the infrabasals will either become absolutely narrower by resorption or relatively narrower by adding material to their distal ends more rapidly than to the sides (Fig. 14d), and the crinoid lineage will tend to develop cups with deep, concave bases.

(5) The flare of the distal cup walls can be affected by the manner in which growth increments are added to the radials. If material is added evenly to the radials at the interradial sutures, no change in cup morphology will take place if the radial walls are vertical. If the radial walls slope inward, evenly added increments may cause some bulging near the basal plane of the cup; if the walls slope outward, evenly added increments may cause some expansion to take place near the summit of the cup.

(6) If radial growth increments are added in pie slices, no change in cup morphology or cross section should occur. If material is added nearer to the proximal ends of the interradial sutures faster than to the distal ends, bulging of the base and constriction of the summit should result. If the distal ends of the radials are enlarged faster, the radials could be expected to flare outward near the articular facets (e.g. *Erisocrinus* from Melvern, Kansas, and some *Erisocrinus* from the Mound at Bartlesville, Oklahoma.) The cup may become elongated by the addition of material at infrabasal-basal and basal-radial sutures.

(7) Probably the most important point to be made is that the base of a crinoid does not necessarily become more convex, more conical, etc. Changes in the nature of the base may be, rather, manifestations of changes in growth trends of individual plates, especially in the infrabasal and basal circlets. Changes in cup cross section, on the other hand, may point out changes in growth trends, especially, the infrabasal and basal circlets. Our knowledge of crinoid growth, evolution, and phylogeny will not expand or even change as long as we study and observe only the end products of growth trends. Rather, our attentions should be shifted to the causes bringing about changes in the base, cup outline, cup cross section, etc.

(8) The addition of stereom to the plate surfaces is also important. Many immature crinoids show deep indentations at suture junctions (e.g. *Endelocrinus* Moore and Plummer, 1940). This feature may be of more ontogenetic than generic importance. It is used in part to differentiate *Endelocrinus* Moore and Plummer from *Delocrinus* Miller and Gurley. On the other hand, pirasocrinids with depressions at suture junctions are not necessarily assigned to separate genera.

EVOLUTION AND ONTOGENY OF ANAL PLATES

Another problem in crinoid studies may rest in the fact, or at least the strong possibility, that much previous work has not carefully distinguished between evolutionary trends and ontogenetic

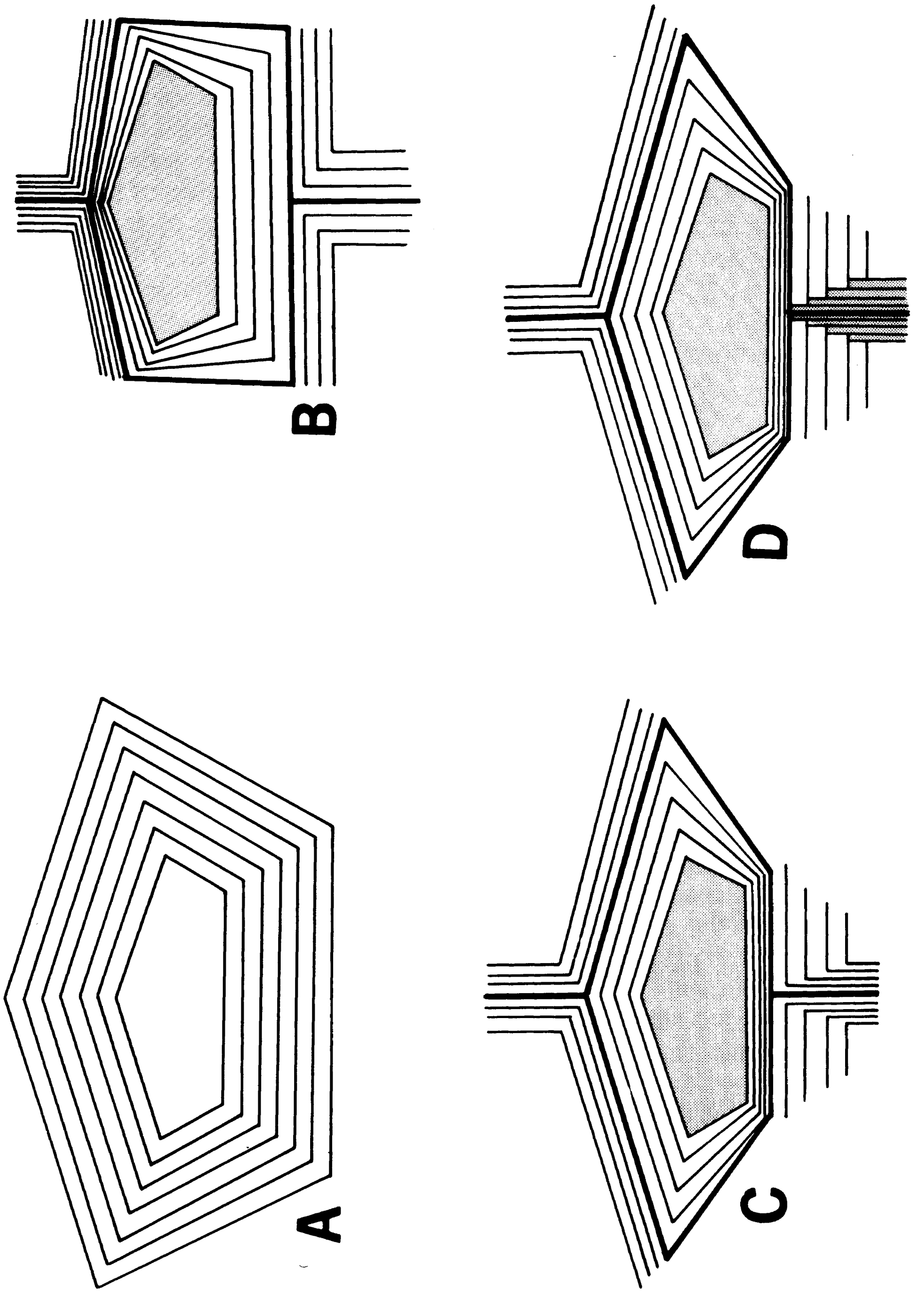

Fig. 14. Hypothetical modes of addition of growth increments to basal plates.

changes. A good example of this problem is the interpretation of expulsion and/or resorption of the anal X plate from the cup. Normal delocrinid anal plate arrangement is shown in Figure 15g, h.

Strimple (1960, pp. 247–253) has shown a number of possible sequences for elimination of anal plates from the crinoid cup. It has been assumed that all such sequences are indicative of an inherent evolutionary process. A condition in which the anal X plate has lost contact with the CD basal causing the C and D radials to touch is probably evolutionary (Figs. 15a, b); the anal X and CD basal probably never touched one another at any time during the crinoid's growth as shown by Figure 15g, h. The addition of growth increments between adjacent plates would preclude the possibility that these plates ever touched.

In another example, however, ontogeny may be considered as a possibility for the "expulsion" of the anal X plate. If the anal X plate does not appear in part of the outer wall of the cup (Figs. 15c, d) but is merely a triangular element on the inner cup wall, the seeming "expulsion" may merely be an ontogenetic feature. If such an anal X plate contacts the CD basal in the interior of the cup (Fig. 15e), ontogenetic causes may be strongly suspected; whereas if such contact is lost (Fig. 15f), evolution should be suspected.

The anal X plate of some cups carries posteriorly directed, laterally situated facets presumably to accommodate the primibrachials when the arms of the crinoid were in a closed position. As growth of the crinoid continued and material is added to the C and D radials at the CD interradius (Fig. 15i), these plates may eventually overlap the small sutures on the anal X plate (Fig. 15j). The net result is that the parts of the anal X plate that were once exposed on the outer cup wall are covered by the outer parts of the radials (Fig. 15j). The anal X plate, in this case, is not expelled from the cup but is merely reduced in importance as a visible cup element. *Kansacrinus* n.g. (=*Oklahomacrinus discus* Strimple) from Melvern, Kansas, also provides an example of the C and D radial plates overlapping the anal X plate (Fig. 15k).

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Specimens reposited at the University of Nebraska State Museum have the UNSM prefix.

SYSTEMATIC PALEONTOLOGY

Phylum:	ECHINODERMATA Bruguiere, 1789
Subphylum:	CRINOZOA Matsumoto, 1929
Class:	CRINOIDEA Miller, 1821
Subclass:	INADUNATA Wachsmuth and Springer, 1885
Order:	CLADIDA Moore and Laudon, 1943
Suborder:	POTERIOCRININA Jaekel, 1918
Superfamily:	ERISOCRINACEA Wachsmuth and Springer, 1886
Family:	CATACRINIDAE Knapp, 1969

Type Genus.—*Catacrinus* Knapp, 1969, p. 365 [=*Delocrinus* Miller and Gurley, 1890, p. 9 (junior objective synonym, having identical type species)]

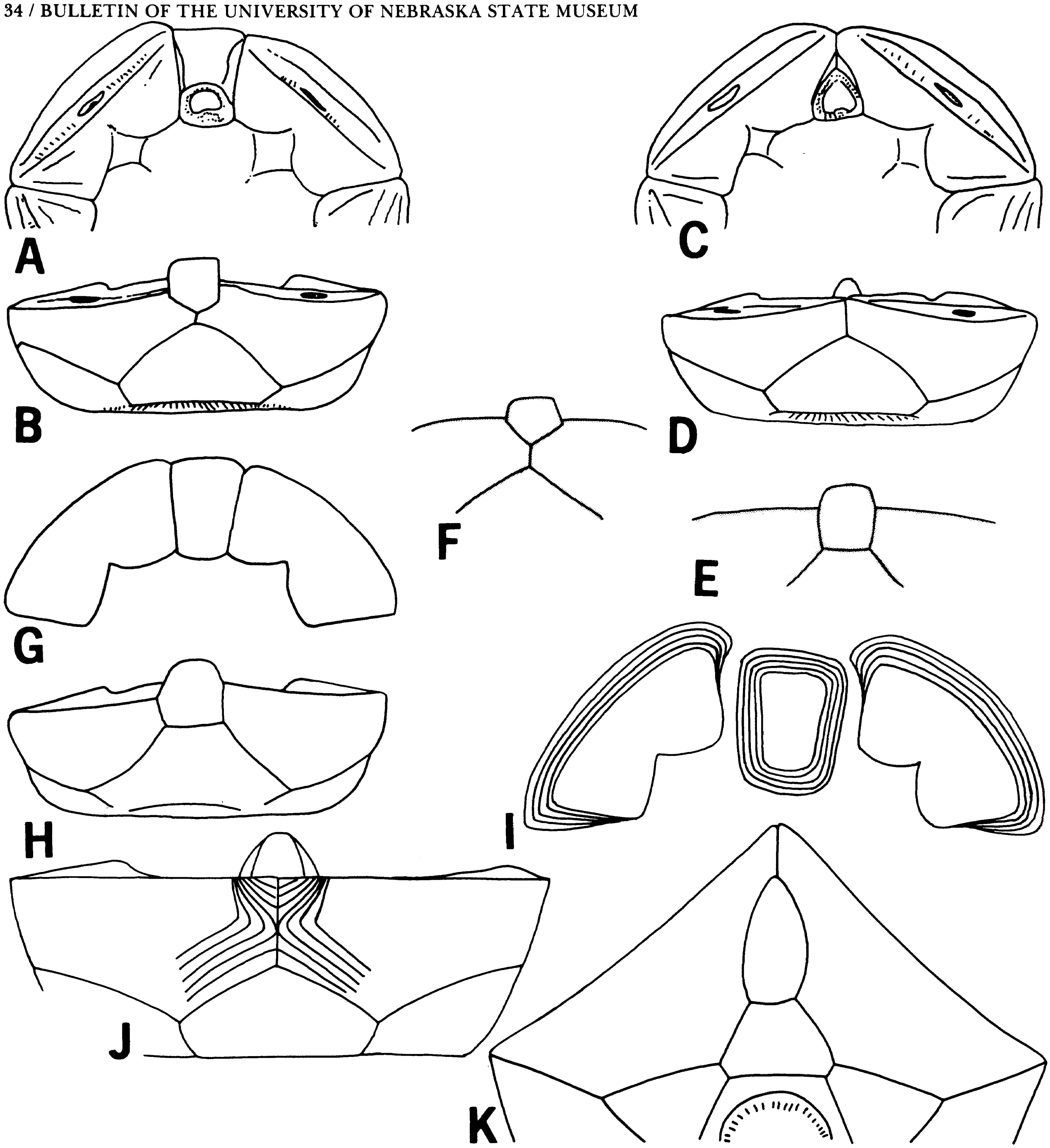

Fig. 15. Evolutionary versus ontogenetic traits in disposition of anal X plates in delocrinid and graffhamicrinid (A–J), and cymbiocrinid (K) cups. A, B. Summit and posterior views of evolutionary elimination of anal X plate, compared to normal retention of anal X plate G, H. C, D. Summit and posterior view of either evolutionary elimination or ontogenetic concealment of anal X plate. E, F. Interior regions of posterior interray. If, in Figs. C, D, the anal X plate still contacts the CD basal inside the cup (Fig. E) the "elimination" of anal X is likely ontogenetic, as plate growth increments are added by the C and D radials around the periphery of anal X, concealing the plate from view only, Figs. I, J. If in Figs. C, D, the anal X has lost contact with the CD basal on the interior of the cup, (Fig. F), the elimination of this plate is likely evolutionary. K. *Kansacrinus discus* with anal X plate enwrapped by C and D radials, showing ontogenetic concealment of this plate. Holotype, USNM S-4733.

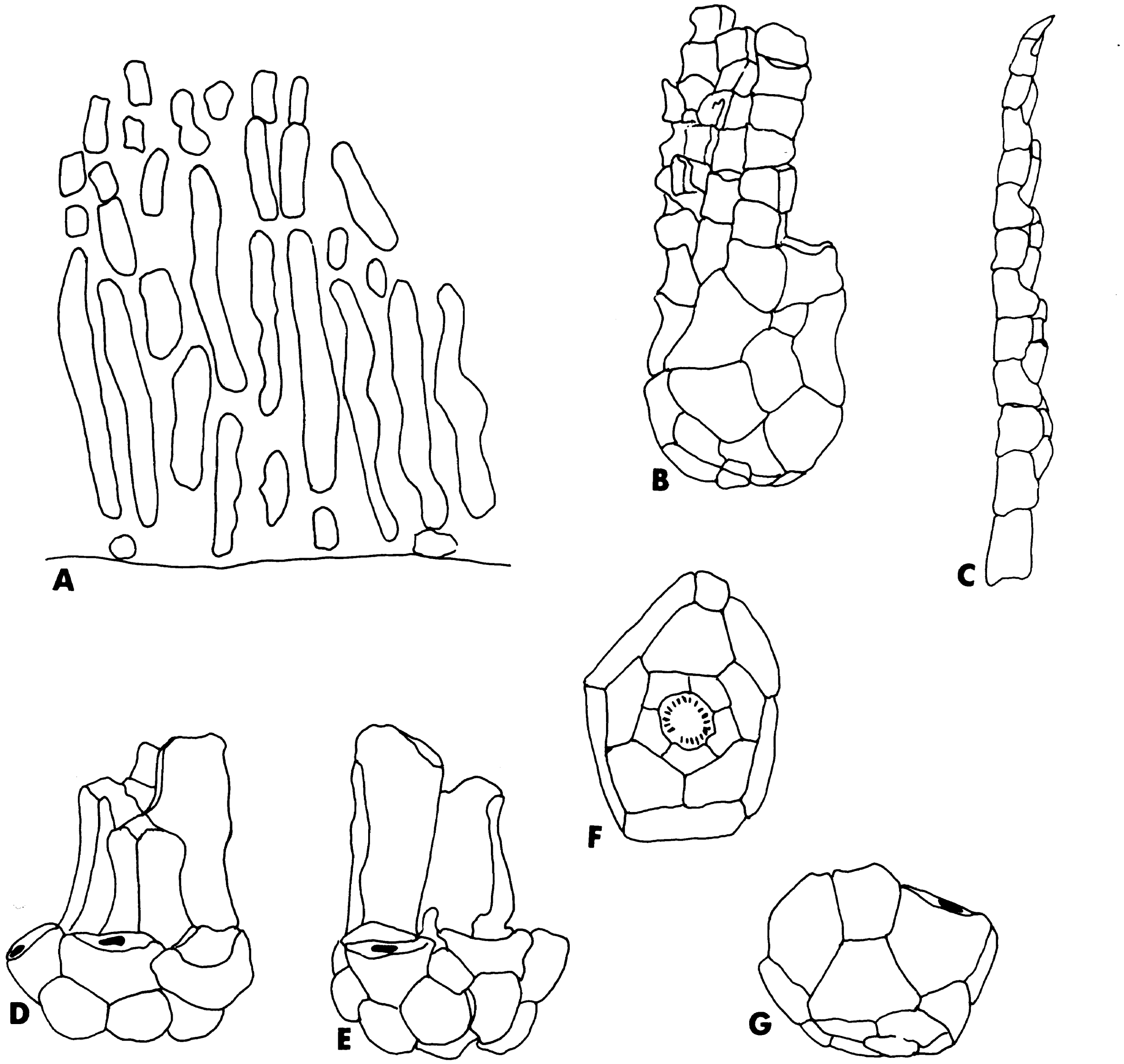

Fig. 16. A. *Grafthamicrinus magnificus* (Strimple). Nature of ornamentation of ridges and small pustules on radial plates of hypotype, USNM 10492, X10. B, C. *Apographiocrinus virgilicus* Pabian & Strimple. B. Hypotype crown in process of eliminating anal X plate, UNSM 16529, from Melvern, Kansas, X10. C. Interior of arm of hypotype crown, UNSM 16530, showing pinnulation on alternate brachials, from Melvern, Kansas, X10. D, E. *Triceracrinus facilis* Strimple. Anterior and posterior views of immature, partial crown. Note diminished PBr1 on E radial and extremely small anal X plate, hypotype, UNSM 16531, from Melvern, Kansas, X4. F, G. *Moundocrinus* sp., basal and posterior views of immature cup, UNSM 8059, from Weeping Water, Nebraska, X10.

[Zoological Code, art. 40a, stipulates that after 1960 family-group names based on junior synonyms (objective or subjective) as type genera prevail over senior synonyms.]

Diagnosis.—Crown moderately tall, cylindrical, with ten closely appressed, biserial, pinnulate arms. Cup low, bowl-shaped, with narrow and deep basal concavity, plate surfaces smooth or rugose; 5 small down-flared infrabasals at bottom of concavity, sides of which are formed by basals or their proximal parts and in some genera by proximal extremities of radials; articular facets of radials plenary and planate; single anal plate in cup, resting on truncate summit of CD basal. Anal sac moderate in height, cylindrical, composed of longitudinal rows of small, polygonal plates. Arms branching isotomously on first primibrach. Stem transversely circular.

Genera.—*Delocrinus* Miller and Gurley, 1890 [=*Catacrinus* Knapp, 1969; *Asaccocrinus* Wanner, 1916; *Wewokacrinus* Knapp, 1969; *Palmatocrinus* Knapp, 1969]. *Cathetocrinus* Knapp, 1969; *Arrectocrinus* Knapp, 1969; [=*Metarrectocrinus* Knapp, 1969]; *Endelocrinus* Moore and Plummer, 1940; *Lobalocrinus* Knapp, 1969; *Palmerocrinus* Knapp, 1969; *Parallelocrinus* Knapp, 1969; *Paraplasocrinus* Moore and Plummer, 1938; *Pyndaxocrinus* Knapp, 1969; *Subarrectocrinus* Knapp, 1969; *Sublobalocrinus* Knapp, 1969.

Range.—Lower Pennsylvanian (Morrowan)–Lower Permian (Wolfcampian), U. S. A., (Texas, Oklahoma, Arkansas, Kansas, Missouri, Nebraska, Iowa, Illinois, Ohio, Nevada).

Genus DELOCRINUS Miller and Gurley, 1890

Type Species.—*Delocrinus subhemisphericus* Moore and Plummer, 1940.

Diagnosis.—Five infrabasals and proximal portions of basals in deep, narrow basal concavity. Medial portion of basals form basal plane of cup. Proximal tips of 5 radials above basal plane, anal X present. Arms, 10, biserial.

Other Species Included.—*Eupachycrinus craigi* Worthen, 1875; *Cyathocrinus inflexus* Geinitz, 1866; *Delocrinus missouriensis* Miller and Gurley, 1890; ? *D. pendens* Moore and Plummer, 1938; *D. verus* Moore and Plummer, 1940; *D. vulgatus* Moore and Plummer, 1940; *D. wewokaensis* Strimple, 1940a; *D. extraneous* Strimple, 1949a; *D. ponderosus* Strimple, 1949b; *D. brownvillensis* Strimple, 1949b; *D. vastus* Lane and Webster, 1966.

Remarks.—The status of the genus *Delocrinus* has been doubtful for many years, the problem beginning with an unillustrated description (Shumard, 1858) becoming compounded by the destruction of the type specimen(s) in the Swallow Hall fire, and the subsequent placement of the genus in a *nomen dubium* status (Knapp, 1969, p. 367). Moore and Strimple (1970, pp. 202–204) petitioned the International Commission on Zoological Nomenclature (ICZN) to designate the holotype specimen of *Delocrinus subhemisphericus* as the neotype specimen of *Poteriocrinus hemisphericus* Shumard, 1858. Moore and Plummer (1940, p. 258) renamed Miller and Gurley's specimen *Delocrinus subhemisphericus*, assuming the latter had misidentified their specimens. Article 70 of the Zoological Code (1961, 1964) states that "a nominal species designated by an author as the type species of a new genus is presumed to have been correctly identified. . . ." Because Moore and Plummer's reference was permitted rather than enjoined (by the Code in effect in 1940, Art. 70a) a pardon for their failure to proceed in such a way to assume Miller and Gurley had properly identified their material was requested. In addition, they requested that Miller and Gurley's specimens (Moore and Plummer's *D. subhemisphericus*) be designated neotypes of *Poteriocrinus hemisphericus* Shumard and, thus, neotypes of *Delocrinus* Miller and Gurley. Such action would make *Delocrinus subhemisphericus* a junior objective synonym of *P. hemisphericus*. The above petition was honored by the ICZN as opinion 1006 (1974, p. 153–154) and the genus *Delocrinus* was allowed to stand.

It appears that several lineages of *Delocrinus* were living in Early Virgilian time. No attempt will be made here to erect new species of *Delocrinus* for several reasons. First, the visible evolutionary tendencies make it impossible to determine when any individual specimen of a new species had attained sufficient characteristics to warrant placing it in another species. Second, only readily observable evolving characteristics have so far been noted; subtle features may prove to be more important to studying evolutionary tendencies. Finally, the authors are now working on a comprehensive study of *Delocrinus* using a very large sample as a control group. To facilitate the study of *Delocrinus* in this paper and in subsequent reports, an evolving species will be compared to that species which we feel is most likely to be its antecedent.

Range.—Middle Pennsylvanian (Desmoinesian)–Upper Permian (Ochoan), U.S.A., (Virginia, Pennsylvania, Ohio, Illinois, Iowa, Missouri, Nebraska, Kansas, Oklahoma, Texas, Nevada); Eastern Pacific, (Island of Timor); South America, (Brazil, Bolivia).

***Delocrinus vulgatus* Moore and Plummer, 1940**
Figs. 3, 4, 5, 6, 17a–j, 18a

Delocrinus vulgatus Moore and Plummer, 1940, pp. 286–288, pl. 18, figs. 1, 2; Moore and Laudon (in Shimer and Shrock) 1944, p. 173, pl. 65, fig. 19; Pabian and Strimple, 1974a, pp. 266–267; pl. 35, figs. 10–12; 1974b, p. 14, figs. 17, 18a; 1980a, pp. 9–10, pl. 2, figs. 7–9.

Description.—This species is represented by 88 dorsal cups, 14 of which have the lower parts of the arms attached on one or more rays. Cup cross section varies from a low to a medium bowl. Five infrabasals small, situated in a deep, narrow, funnel-like to medium-shallow basal concavity; their proximal and medial portions are covered by proximal columnals, their distal portions slope down and out from the basal concavity.

AB, BC, DE, and EA basals pentagonal, their proximal portions confined to the basal concavity, and sloping downward and outward at about 45 degrees. CD basal usually hexagonal, its distal end truncated for reception of large, normally 6-sided anal X plate. Basal plane of cup formed by medial portions of basals. Distal ends of basals slope upward and outward from basal plane, extending about half the height of the cup and terminating at a distal tip situated in each interray. Basals tumid in small cups, smooth in large. Five epaulette-shaped radials tumid on small individuals, but show little relief on large; their proximal tips extend nearly to the basal plane. Radials slope steeply at about 60 degrees and curve inward near the cup summit. Anal X large, situated between C and D radials, and faceted for reception of tube plate.

Sutures between cup plates range from indistinct to slightly impressed and distinct. There may be a moderate depression at the plate-suture junctions in small specimens. In larger specimens, depressions become faint dimples and are entirely absent on largest individuals.

Radial articular facets wide, well detailed. Outer marginal ridge sharp, separated from transverse ridge by narrow, moderately deep outer ligament furrow. Ligament pit deep, well defined. Transverse ridge wide, finely denticulate, separated from non-denticulate oblique ridge by a moderately broad lateral furrow. Lateral ridge prominent. Adsutural slope narrow. Muscle areas well defined; sloping inward to a broad central pit that connects to a V-shaped intermuscular notch by way of a fairly broad intermuscular furrow.

Primibrachials axillary, epaulette-shaped, slightly protruded, those on B and E rays being shorter than the others. First secundibrachials trapezoidal; wedge-shaped to cuneiform secundibrachials follow.

In small specimens, the first 3 to 7 secundibrachials are uniserially arranged (Figs. 17i, j), their arrangement becoming equi-biserial thereafter. Large individuals show only biserially arranged secundibrachials in the lower portions of arms (Fig. 17h). One specimen (UNSM 12541) shows coarse nodes on the lower portion of each arm (Fig. 18a).

Columnar cicatrix round, crenulated; lumen pentalobate.

Remarks.—This species appears to be closely related or, possibly, conspecific with *Delocrinus inflexus* (Geinitz), 1866. Geinitz's species, *Cyathocrinus inflexus*, was collected from Horizon 49 at Nebraska City, Otoe County. This horizon is probably in either the Langdon Shale or in the Dover Limestone of Late Virgilian age. Moore and Plummer (1940, p. 287) indicated that *D. inflexus* is distinctly wider and has more flaring sides than *D. vulgatus*. They also indicated that the height/width ratio of the cup of *D. inflexus* was 0.50 (p. 254) and that this ratio varied from 0.35 to 0.37 (p. 287) for *D. vulgatus*. The samples from Weeping Water have cups with height/width ratios ranging from 0.308 to 0.415, whereas cups

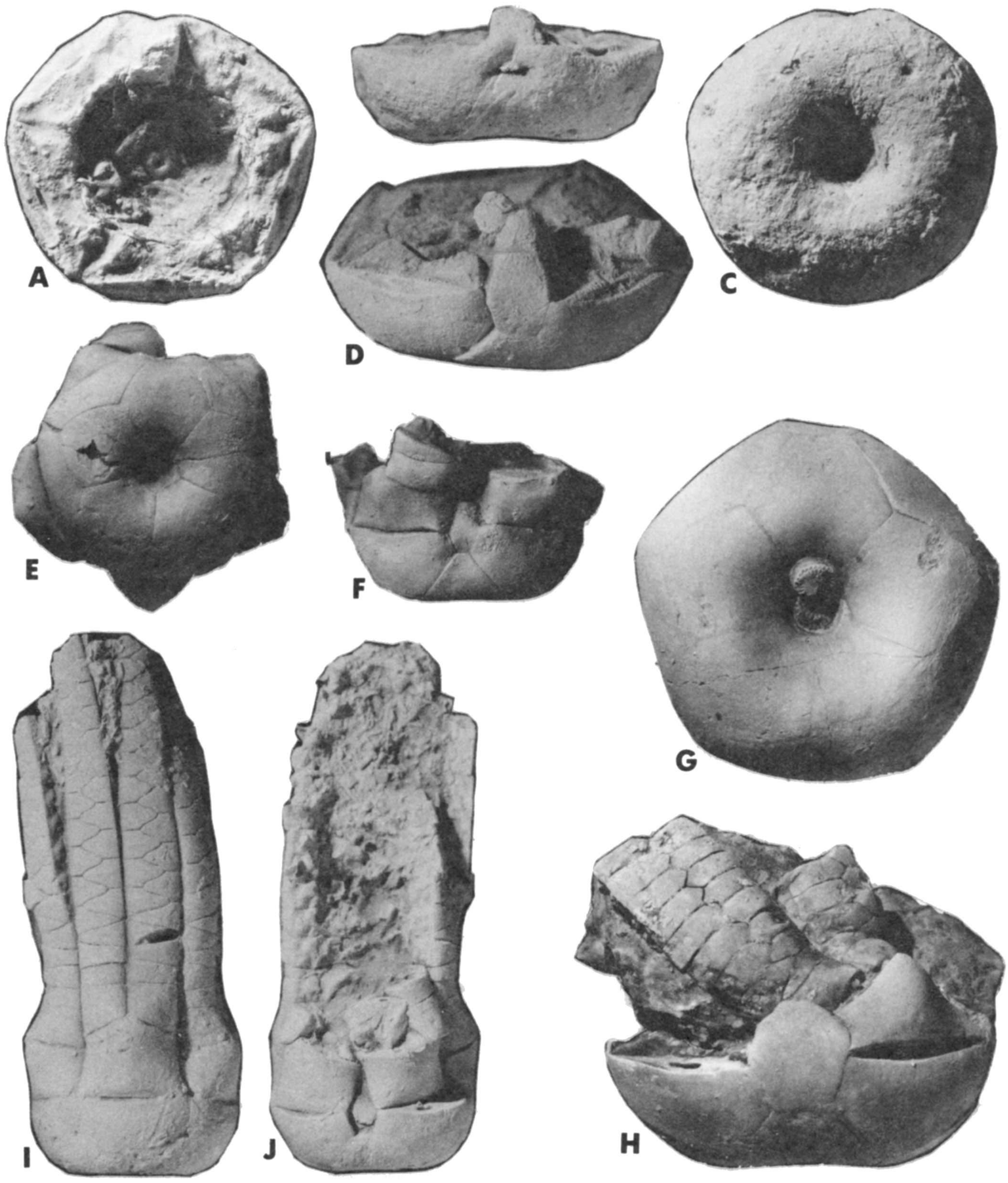

Fig. 17. *Delocrinus vulgatus* Moore and Plummer from Ace Hill and Weeping Water, Nebraska. A–C. Hypotype, UNSM 8067, Weeping Water, summit, posterior and basal views, X4. D. Hypotype, UNSM 12507, Ace Hill, posterior view showing two tube plates, X3. E, F. Hypotype, UNSM 8005, Weeping Water, basal and posterior views, X2. G, H. Hypotype, UNSM 8003, Weeping Water, basal and posterior views, X2. I, J. Hypotype, UNSM 12539, Ace Hill, anterior and posterior views, X2. Note only slightly protruded primibrachials (E, F, H, I, J) and uniserial nature of lower arms in small crowns compared to biserial nature of lower arms of large cup with attached arm in C ray (H).

from Ace Hill have height/width ratios ranging from 0.326 to 0.446. Moore and Plummer commonly used the width of the cup as the widest area perpendicular to the antero-posterior axis. Moore and Plummer determined the height/width ratio for *D. inflexus* from a plastoholotype. Since our samples show considerable variation in height/width ratios, and a possibility of overlapping with those known for *D. inflexus*, and since cups of *D. inflexus* appear much like cups of *D. vulgatus*, we retain the latter species with some reservation. The location of the holotype specimen of *D. inflexus* is not now known; it was in Germany at the beginning of World War II.

Specimens of *Delocrinus vulgatus* from both Ace Hill and Weeping Water vary within rigidly fixed limits. These limits are summarized below. There is some variation in the basal concavity of *D. vulgatus*, and this appears to be at least partially controlled by ontogeny. The basal concavity ranges from constricted and shallow, wide and shallow, wide and medium, wide and deep, to constricted and deep. The more shallow basal concavities are usually on smaller cups; deeper concavities on larger ones, with some overlap in the medium sizes. The basal concavities of most of the specimens examined retain the stem impression on the infrabasal disc, though the stem is rarely preserved intact. Thus, it is easy to study the variations of the basal concavities.

The basal plane of the cup is confined to the medial third of the basal circlet, as measured from the proximal edges of the basals; this shows almost no variation. The basal plane is most pronounced at the interbasal sutures where there may be low projections, whereas the medial portions of the basals curve inward slightly. The distal tips of the basals rise about half the height of the cup at their interradial junctions. The proximal tips of the radial plates rarely extend to the basal plane of the cup.

Sutures between plates are normally distinct but not impressed. Dimples at suture junctions are restricted to small specimens (Figs. 17b, 18a), many of which would probably be assigned to *Endelocrinus* if they could not be placed in a growth sequence. Some sutures have numerous, short parallel lines arranged perpendicular to them, producing a "stitched together" appearance. Although this feature is not always discernible, it has been reported on specimens of *D. brownvillensis* from the Brownville Limestone Member, Kanawa Formation (Virgilian) exposed near Fairfax, in Osage County, Oklahoma, by Pabian and Strimple (1973, p. 19).

The anal X plate varies in shape and position. In a few specimens, the plate is wedge-shaped and separated from the CD basal. Some anal X plates are narrowly rectangular, whereas others are widely rectangular, or barrel-shaped. The latter tend to be most prominent on large specimens.

Delocrinus vulgatus showed no tendency to expel the anal X plate. The idea is entertained here that in any given population of crinoids, some individuals expelled the anal X plate and others retained it. Early in the evolutionary history of a species, rare individuals will eliminate this plate, but most will retain it. At some later time, the majority of individuals may expel the anal X plate and rare ones will retain it. The movement of the anal X plate out of the cup may be either an evolutionary or ontogenetic character, as indicated earlier in this study. The anal X is followed by 2 or more tube plates (Fig. 17d).

First primibrachials vary from slightly protruded to slightly spinose (Figs. 17e, f, h, i, and j). This appears to be unrelated to ontogeny, some smaller individuals having more spinose primibrachials and some larger ones having slightly protruded ones, or vice versa.

The first secundibrachial is a trapezoidal, nonaxillary element. In young individuals subsequent brachials are uniserial, grading upward to cuneiform, and finally biserially-arranged plates. From 3 to 7 brachials may be involved in this transition. On the largest individuals, the first secundibrachial is trapezoidal and is immediately followed by biserial secundibrachials (Fig. 17h). If the smaller specimens could not have been placed in a growth sequence, they probably would have been assigned to *Endelocrinus*.

Cups of *Delocrinus vulgatus* may be low or medium bowls or any shape in between. In low bowls, the distal portions of the radials slope at an angle of about 45 degrees to the basal plane; but in medium bowls, the distal half of the radials is nearly vertical. The height/diameter ratio varies from 0.308 to 0.446.

One individual (UNSM 12541) shows some wart-or tumor-like growth on the AB and EA basals, but these are not interpreted to be ornamentation.

Though the dorsal cup of *Graffhamicrinus decapodos* Strimple and Priest varies considerably from that of *D. vulgatus*, the arms of one specimen of *D. vulgatus* are nearly identical to those of *G. decapodos* (Fig. 17a). Strimple and Priest (1969, p. 23) envisioned *G. decapodos* as capable of using its arms to form a decapod on which the crown could rest while the animal was feeding. They indicated that the knobs on the primibrachials rested on projections on the radials; the lower parts of these were directed downward, their nodose sections resting on the muddy sea bottom.

There is generally looser niche segregation in marine communities, especially among non-selective suspension or filter feeders. We suggest that some individual variants of *D. vulgatus* probably were similar, not only morphologically but also functionally, to *Graffhamicrinus decapodos*. Since the arms of the crinoid meet the environment *head on* in these species, these arms underwent the most change to adapt to the open niches in the surrounding environment; thus, entirely different cups may have remarkably similar arms. Homeomorphism should be carefully considered in all subsequent studies of *Delocrinus* and *Graffhamicrinus.*

Material Studied.—Hypotypes, UNSM 8001–UNSM 8028; UNSM 8064–UNSM 8070; UNSM 8074; UNSM 12541, all from Weeping Water, Nebraska. Hypotypes, UNSM 12534–UNSM 12537, UNSM 12473–UNSM 12518, UNSM 12539, all from Ace Hill Quarry, Nebraska. UNSM 10490, Stull Shale Member of the Kanwaka Formation in the Shawnee Group of the Virgil Series, C NE¼, sec. 27, T. 73 N., R. 38 W., Montgomery County, Iowa. UNSM 17425, SW¼ NW¼, sec. 29, T. 73 N., R. 43 W., Montgomery County, Iowa.

Delocrinus sp. cf. *D. subhemisphericus* Moore & Plummer, 1940

Figs. 18b–d, 27a

Description.—Infrabasal circlet with 5, kite-shaped, nearly flat-lying plates confined to a broad, shallow concavity; a deep cusp at each suture gives a stellate outline to this circlet. Columnar cicatrix pentalobate, deeply impressed, and covers about one-half the diameter of the circlet.

There is a sharp bend at the junction between the basal and infrabasal circlets. Proximal portions of basals slope gently downward, medial portions form basal plane of cup, and distal portions rise about one-third the height of the cup. AB, BC, DE, and EA basals pentagonal; CD hexagonal, truncated for reception of hexagonal anal X plate.

Five radials epaulette shaped, curving inward gently near cup summit; C and D separated by anal X plate.

Radial-articular facets with blunt, poorly defined outer marginal ridge. Outer ligament furrow wide, shallow. Ligament pit deep, bounding nondenticulate transverse ridge. Oblique ridges well-defined, non-denticulate lateral ridges of adjacent plates separated by deep notch formed by abutting adsutural slopes. Muscle areas slope inward to a broad, shallow central pit that is divided into two equal halves by a faint ridge. Intermuscular notch and furrow both faint.

Remarks.—These specimens most closely compare to ones described as *Delocrinus hemisphericus* by Pabian and Strimple (1974a, pp. 263–265). The basal concavity appears to be evolving from deep and narrow to broad and shallow. The end product of this lineage is possibly a species such as *Pyndaxocrinus separatus* (=*D. separatus*).

Material Studied.—Hypotypes, SUI 37707, Melvern, Kansas, and USNM 247904 and USNM 247905, Melvern, Kansas. UNSM 23344, from Melvern, Kansas.

Genus ENDELOCRINUS Moore and Plummer, 1940

Type Species.—*Eupachycrinus fayettensis* Meek and Worthen, 1873.

Diagnosis.—Cup low, discoid. Infrabasals 5, confined to medium concavity; basals 5, bulbous; radials 5, bulbous; single anal plate. Facets plenary, flat lying. Primibrachials protruded. Arms 10, uniserial in lower portions.

Other Species Included.—*Delocrinus texanus* Weller, 1909; *Endelocrinus rotundus* Strimple, 1963; *Delocrinus allegheniensis* Burke, 1932; *E. grafordensis* Moore and Plummer, 1940; *D. tumidus* Strimple, 1939a; *E. parvus* Moore and Plummer, 1940; *E. mitis* Moore and Plummer, 1940; *E. bransoni* Strimple, 1962a; *D. matheri* Moore and Plummer, 1938.

Remarks.—Moore and Plummer (1940, pp. 296–297) erected *Endelocrinus* to receive delocrinids with transverse and longitudinally convex basals and radials which appeared distinctly bulbous, or delocrinids with sharp inflections at the borders of basals and radials. The arms are uniserial in the lower 7 or 8 segments. Careful review of these criteria should be made to establish the validity of *Endelocrinus*. Moore and Plummer (1940) and Strimple (1950a) indicated that *Endelocrinus* was quite small for a delocrinid. It is suggested here that some species assigned to *Endelocrinus* are growth stages of *Delocrinus*.

Endelocrinus sp. cf. *E. tumidus spinosus* Strimple, 1950a

Figs 18e–k

Delocrinus tumidus Strimple (portion) 1939a, p. 8, pl. 2, figs. 1–8.

Endelocrinus tumidus spinosus Strimple, 1950a, p. 112.

Tholiacrinus tumidus (portion) Strimple (Knapp), 1969, p. 367.

Endelocrinus tumidus spinosus Strimple (Pabian and Strimple) 1974a, p. 279, pl. 37, figs. 4–5.

Remarks.—This species was found only at Melvern, Kansas. The smallest individuals have somewhat bulbous plates, whereas the larger individuals have small dimples at plate junctions. One specimen (SUI 37705) has the lower portions of the arms preserved in the B ray (Fig. 18k). The arms become biserial at the 6th and 7th secundibrachials. The specimen has a fairly long, spinose primibrachial rather than a short, slightly protruded one [cf. *Delocrinus vulgatus*, (Figs. 17i, j)].

We retain this designation with some reservation because the Melvern specimens are few in number and a growth series from this location has not been established.

Material Studied.—Hypotypes SUI 37699, SUI 37702, SUI 37705, and UNSM 23332, all from Melvern, Kansas.

Genus PYNDAXOCRINUS Knapp, 1969

Type Species.—*Delocrinus separatus* Strimple, 1949a.

Diagnosis.—Base flat or shallowly concave; infrabasals subhorizontal, basals 5, radials 5, anal X present; arms unknown.

Other Species Included.—*Pyndaxocrinus gerdesi* Pabian and Strimple, 1974a. *Pyndaxocrinus inornatus* Pabian and Strimple, 1980a.

Range.—Upper Pennsylvanian (Virgilian) U.S.A.; Nebraska, Kansas, Iowa.

Pyndaxocrinus separatus (Strimple), 1949a

Figs. 26a, b

Delocrinus separatus Strimple, 1949a, pp. 276–277, pl. 39, figs. 4–7.

Emended Description.—Emended to Strimple, 1949a, pp. 276–277. A damaged, partial topotype cup shows the infrabasal circlet; EA, AB, and BC basals; and the A and B radials. Cup plates thick, covered with fine, granulose ornamentation. Radial articular facets plenary, nearly flat lying, but with very high relief. Outer marginal ridge well defined; outer ligament furrow shallow; outer ligament ridge poorly defined, slightly denticulate; transverse ridge low, denticulate; lateral furrows deep; oblique ridge recumbent; muscle areas large, sloping into large central pit that occupies about one-third the total facet area; lateral ridge high; adsutural slope about 45 degrees.

Remarks.—The cup is covered with some thin, delicate worm tubes, but no other commensal or parasitic organisms were observed.

Material Studied.—Topotype UNSM 11846, from Melvern, Kansas.

Pyndaxocrinus sp. cf. *P. gerdesi* Pabian and Strimple, 1974a

Figs. 18l–n

Pyndaxocrinus gerdesi Pabian and Strimple, 1974a, pp. 274–275, pl. 35, figs. 5–7, pl. 36, fig. 6.

Remarks.—This specimen has a mildly impressed base; otherwise, it is identical to the

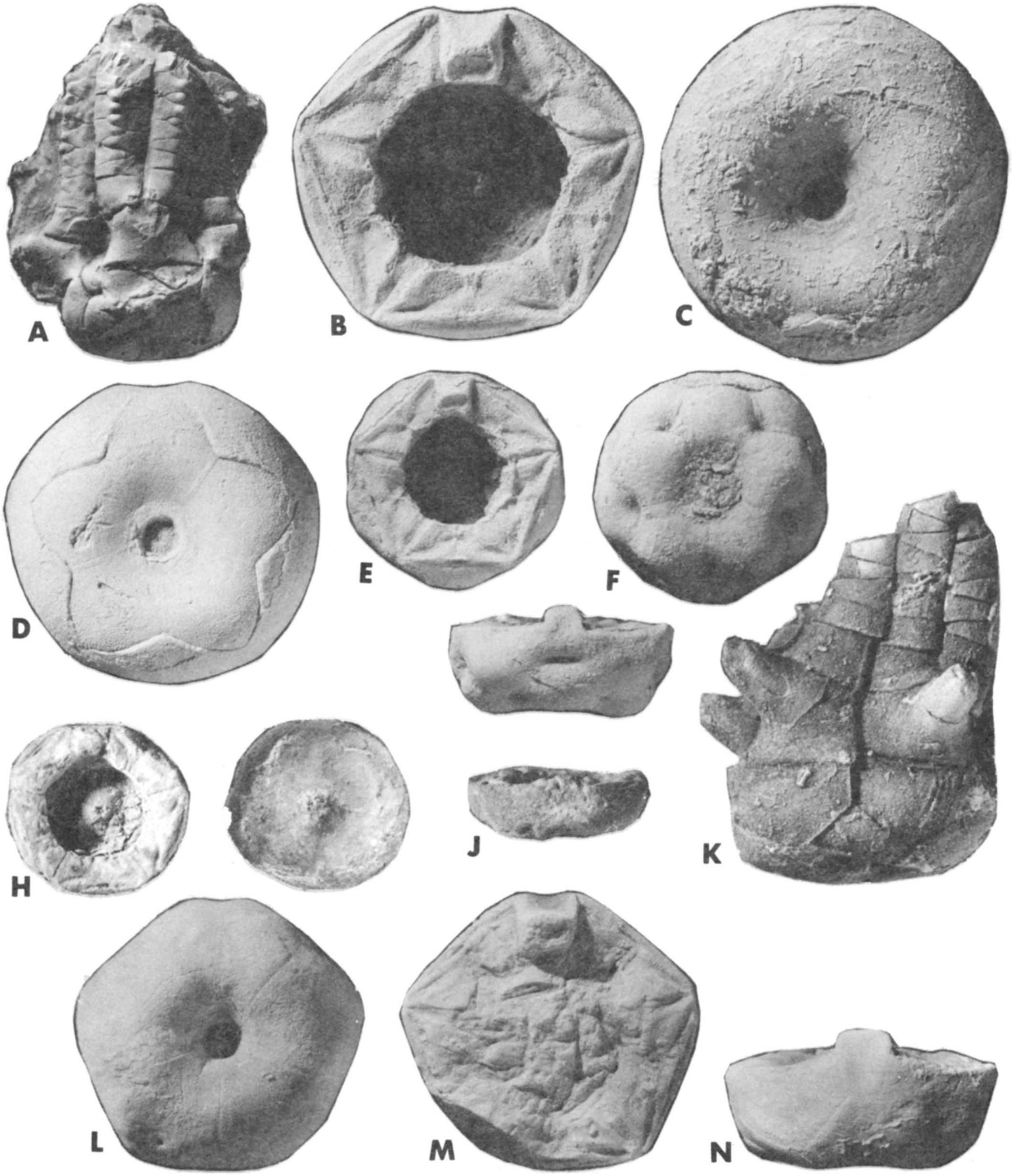

Fig. 18. A. *Delocrinus vulgatus*, hypotype, UNSM 8064, Ace Hill, X2. Note warty protrusions on lower brachials [cf. *Graffhamicrinus decapodos* Strimple and Priest, 1969, pp. 23–25)]. B, C, D. *Delocrinus* sp. cf. *D. hemisphericus* (Shumard), hypotypes. B, C. USNM 247904 and D, USNM 247905 both from Melvern, Kansas, X2. E–K. *Endelocrinus* sp. cf. *E. tumidus spinosus* (Strimple). E–G. Hypotype, UNSM 17699, X3. H–J. Hypotype, SUI 37702, X3, from Melvern, Kansas. K. Hypotype, SUI 37705, Melvern, Kansas, L–N. *Pyndaxocrinus* sp. cf. *P. gerdesi* Pabian and Strimple, Hypotype, UNSM 12498, Ace Hill, X2.5.

holotype specimen *P. gerdesi. P. separatus* is the oldest known representative of this genus; it has a flat base and is delicately granular in surface ornamentation. *P. gerdesi* has a much deeper cup in addition to a smooth surface. Specimens in current collections indicate that *P. separatus* and *P. gerdesi* are in separate lineages having a common ancestor. The line represented by *P. gerdesi* shows a strong tendency to retain a primitive, flat base. *P. inornatus* has a smooth to finely granular cup, a shallowly impressed base, and a low profile, indicating closer affinities to *P. separatus* than to *P. gerdesi.*

Material Studied.—Hypotypes, UNSM 12498, from Ace Hill Quarry. UNSM 17421, from Weeping Water.

Genus CATHETOCRINUS Knapp, 1969

Type Species.—*Delocrinus stullensis* Strimple, 1947.

Diagnosis.—Basal concavity broad and shallow; proximal tips of radials in basal plane of cup; sides of cup erect. (After Knapp, 1969, p. 362).

Other Species Included.—*Graffhamicrinus boellstorffi* Pabian and Strimple 1974b.

Range.—Upper Pennsylvanian (Virgilian)–Lower Permian (Wolfcampian), U.S.A., (Nebraska, Kansas).

Cathetocrinus stullensis (Strimple), 1947

Figs. 20i–k, 24a–c

Delocrinus stullensis Strimple, 1947, p. 506, pl. 2, figs. 406, table 15.

Graffhamicrinus stullensis (Strimple) Pabian and Strimple, 1974a, p. 272, pl. 33, figs. 4–5; 1974b, p. 32, figs. 15, 1, 3.

Cathetocrinus stullensis (Strimple) Knapp, 1969, pp. 361, 362

Emended Description.—Emended to Strimple, 1947, pp. 5–6. Primibrachials spinose, axillary, followed by large, trapezoidal SBr1, and small, trapezoidal SBr2; succeeding SBr3 to SBr20 biserial, tapering toward apex of crown. SBr1, SBr2 covered with medium granules; upper brachials smooth.

Remarks.—Pabian and Strimple (1974a, b) discussed a lineage of *Cathetocrinus* (=*Graffhamicrinus*) *stullensis* that have cups which are low in the C and D rays and high in the A and B rays producing a lopsided cup profile. The hypotype on which the description of the arms is based (UNSM 12515) has a normal cup, whereas another hypotype from Ace Hill (UNSM 12477) has the elongated anterior rays. Hypotype (UNSM 10491) from Melvern, Kansas, also shows the elongated anterior rays. A hypotype (UNSM 13315) from the Soldier Creek Shale (Virgilian) exposed in Pawnee County, Nebraska, has elongated A and B rays.

On the basis of the few specimens of *C. stullensis* known, the elongation of the A and B rays appears to be more pronounced in geologically younger specimens. This suggests a definite tendency of some lineages to develop elongate A and B rays. The end product of such evolution is not known. The lineage which has no elongated anterior rays may have given rise to the Permian species, *C. boellstorffi.*

Cathetocrinus stullensis appears to be a form common to the Upper Virgilian strata of Nebraska. If the fossils in the Stull Shale at Melvern, Kansas, are reworked, as suggested earlier in this study, the value of this species as an index fossil will be somewhat limited since the lower range would not be currently established.

One topotype specimen, UNSM 23333, has a partially eliminated anal X plate.

Material Studied.—Hypotypes, UNSM 12477, UNSM 12515, both from Ace Hill; UNSM 10491, Stull Shale Member of the Kanwaka Formation, Kaser Construction Company Quarry, C, NE¼, sec. 27, T. 73 N., R. 38 W., Montgomery County, Iowa. UNSM 13315, collected by Gordon C. Baird, Soldier Creek Shale Member, Burlingame Limestone Formation, exposed in roadcut in SW¼ SE¼ SW¼, sec. 30, T. 3 N. R. 12 E., Pawnee County, Nebraska. Topotypes, UNSM 16540, UNSM 23333, USNM 247911, Melvern, Kansas. Topotype, UNSM 7990, Wakarusa Limestone Member, Bern Formation, Virgil Series (Upper Pennsylvanian), SE¼ SW¼, sec. 2, T. 8 N., R. 10 E., Otoe County, Nebraska, collected by Charles Messenger.

Genus ARRECTOCRINUS Knapp, 1969

Type Species.—*Delocrinus abruptus* Moore and Plummer, 1940, pp. 289–292.

Diagnosis.—Infrabasals 5, in fairly shallow concavity. Basal plane of cup formed by proximal parts of 5 basals. Radials 5, with plenary facets. Anal X barrel shaped.

Other Species Included.—*Arrectocrinus comminutus* Pabian and Strimple, 1974a; *A. hopperi* Pabian and Strimple 1977a; *A. stanleyi* Pabian and Strimple, 1977a; *A. iowensis* Pabian and Strimple, 1980a.

Range.—Late Pennsylvanian (Missourian, Virgilian), U.S.A., (Nebraska, Iowa, Kansas).

Arrectocrinus iowensis Pabian & Strimple, 1980
Figs. 27e–g.

Arrectocrinus iowensis Pabian and Strimple, 1980a, p. 7–9, pl. 1, figs. 13–14; pl. 2, figs. 1–3.

Description.—Infrabasals 5, kite-shaped, confined to broad, shallow concavity. Stem round, crenulated, forming vertical wall in infrabasal circlet; lumen pentalobate. AB, BC, DE, and EA basals pentagonal, CD hexagonal, truncated to receive barrel-shaped anal X plate. Radials 5, epaulette-shaped, C and D separated by anal X. Cup plates smooth with only a few granules.

Radial articular facets plenary, level. Outer marginal ridge sharp, separated from denticulate transverse ridge by deep ligament pit furrow and ligament pit; lateral furrow well-impressed, bounded by oblique ridge. Lateral ridge sharp, and adsutural slope quarter round in cross section. Muscle area grades to semi-circular lateral lobe and slopes inward to a shallow central pit that connects to intramuscular notch by a short furrow.

PBr1 axillary, moderately spinose. SBr1 and SBr2 cuneiform, followed by biserial SBr3 and SBr4.

Remarks.—One specimen has the lower parts of the arms preserved in the D and E rays and has the branching pattern described above. The same specimen (UNSM 17429) was badly chewed on by some undetermined boring organism. The primibrachials are a bit less spinose than those on the holotype specimen, which is a much more mature individual.

Material Studied.—Holotype specimen, UNSM 16698, Plattsmouth Limestone Member of the Oread Formation in the Shawnee Group of the Virgil Series. NW¼ SW¼, sec. 17, T. 72 N., R. 38 W., Montgomery County, Iowa. Hypotypes: UNSM 17429, Spring Branch Limestone Member of the Lecompton Formation in the Shawnee Group of the Virgil Series, N½ SW¼ NW¼, sec. 29, T. 73 N., R. 43 W., Mills County, Iowa; UNSM 17426, Stull Shale, same locality. UNSM 17420, W½, SE¼, sec. 20, T. 12 N., R. 14E., Cass County, Nebraska. Hypotype UNSM 22230, NE¼, sec. 27, T. 73 N., R. 38 W., Montgomery County, Iowa.

Genus SUBLOBALOCRINUS Knapp, 1969

Type Species.—*Paradelocrinus iolaensis* Strimple, 1949a.

Diagnosis.—Basal concavity narrow, deep; infrabasals downflaring, basals transversely concave. Arms biserial.

Other Species Included.—*Erisocrinus (Ceriocrinus) planus* White, 1883; *Sublobalocrinus kaseri* Pabian and Strimple, 1980a.

Range.—Late Pennsylvanian (Missourian, Virgilian), U.S.A., (Iowa, Nebraska, Kansas).

Sublobalocrinus kaseri Pabian and Strimple, 1980a
Figs. 27h–j

Sublobalocrinus kaseri Pabian and Strimple, 1980a, pp. 11–13, pl. 3, Figs. 6–10.

Description.—Cup nearly discoid, smooth. Five infrabasals confined to narrow, deep concavity. Infrabasal disc with crenulated stem impression and pentalobate lumen. Proximal tips of 5 basals enter in basal concavity and medial portions form basal plane of cup; basals rise about half the cup height. Basals pentagonal on cups studied here. Radials 5, epaulette-shaped; proximal tips touch basal plane of cup from which they rise in parabolic cross section to cup summit.

Radial articular facets plenary, sloping slightly down and out. Outer marginal ridge sharp, separated from denticulate transverse ridge by deep, narrow ligament pit and ligament pit furrow. Lateral furrow deeply impressed and bounding high oblique ridge that joins with lateral ridge. Adsutural slopes about 45 degrees, but not deep. Lateral lobes round, sloping into broad central pit that connects to a deep intermuscular notch by a short furrow.

Material Studied.—Holotype, UNSM 16680, NW¼, NE¼, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa. Hypotypes UNSM 17428, N½, SW¼, NW¼, sec. 29, T. 73 N., R. 43 W., Mills Co., Iowa. UNSM 17423, W½ SE¼, sec. 20, T. 12 N., R. 14 E., Cass County, Nebraska. UNSM 22231, NE¼, sec. 27, T. 73 N., R. 38 W., Montgomery County, Iowa.

Family DIPHUICRINIDAE Strimple and Knapp, 1966

DIPHUICRINIDAE Strimple and Knapp, 1966, [incl. Graffhamicrininae Knapp, 1969] (Lower Pennsylvanian–Lower Permian).

Type Genus.—*Diphuicrinus* Moore and Plummer, 1938.

Diagnosis.—Crown tall, arms closely apposed, each brachial with pinnule. Arms cuneate to biserial. Cup wider than high, covered with pustules and granules. Base deeply concave, infrabasals downflared. Anal X followed by 2 tube plates. Radial facets plenary, subhorizontal. Stem transversely round. (Modified after Moore and Strimple, 1973).

Genera.—*Diphuicrinus* Moore and Plummer, 1938. *Graffhamicrinus* Strimple, 1961a [=*Tholiacrinus* Strimple, 1962b].

Range.—Lower Pennsylvanian (Morrowan) -Lower Permian (Wolfcampian), U.S.A., (Texas, Oklahoma, Kansas, Nebraska, Iowa, Ohio).

Genus GRAFFHAMICRINUS Strimple, 1961a

Type Species.—*Graffhamicrius acutus* Strimple, 1961a

Other Species Included.—*Graffhamicrinus antiquus* Strimple and Watkins, 1969; *G. tulsaensis* Strimple, 1962c; *G. variabilis* Strimple, 1962c; *Tholiacrinus rimulatus* Strimple, 1962c; *Corythocrinus undulatus* Strimple, 1961a; *Endelocrinus bifidus* Moore and Plummer, 1940; *E. rectus* Moore and Plummer, 1940; *Delocrinus parinodosarius* Strimple, 1940a; *Graffhamicrinus profundus* Strimple, 1971a; *G. tetraspinosus* Pabian and Strimple, 1974a; *Delocrinus brookensis* Burke, 1970; *Endelocrinus pennsylvanicus* Burke, 1970; *?Paradelocrinus decoratus* Burke, 1970; *Tholiacrinus decapodos* Strimple and Priest, 1969. [For species assigned to *Graffhamicrinus* at the time the genus was introduced, see Strimple (1961a, pp. 123–124)].

Remarks.—As originally defined by Strimple (1961a, p. 123), the genus *Graffhamicrinus* included all ornamented forms previously assigned to *Delocrinus.* Strimple indicated that the primibrachials are usually rather short elements, mildly protruded and spine-like but not long spines as in *Delocrinus subhemisphericus* (=*D. hemisphericus*). We have several large collections of both *Delocrius* and *Graffhamicrinus* at our disposal. More comprehensive investigations may prove that many of the species assigned to *Delocrinus* may be more closely related to *Graffhamicrinus* and vice versa. This idea is based on the observation that many of the smooth crinoids have only slightly protruded primibrachials. That is, distinction of *Graffhamicrinus* and *Delocrinus* may have to be based on features other than ornamentation. The goal of future studies will be to identify both lineages and individual crinoids that show either *Diphuicrinus* or *Phanocrinus* ancestries. Such studies will likely result in considerable revision of both *Delocrinus* and *Graffhamicrinus.*

Range.—Middle Pennsylvanian (Atokan)–Lower Permian (Wolfcampian), U.S.A., (Texas, Oklahoma, Nebraska, Kansas, Iowa, Ohio, Pennsylvania, Virginia).

Graffhamicrinus magnificus (Strimple), 1947
Figs. 10, 11, 12, 16a, 19

Delocrinus magnificus Strimple, 1947, pp. 3–5, pl. 1, figs. 1–4, pl. 2, fig. 1.
Graffhamicrinus magnificus (Strimple) Pabian and Strimple, 1974a, pp. 270–271, pl. 33, figs. 9–11; 1974b, p. 15, fig. 6,1; pp. 34–35, figs. 15, 4,6; 16, 1.

Description.—Basal concavity moderately deep. Infrabasals 5, small, kite-shaped with proximal tips covered by round, crenulated columnar cicatrix with pentalobate lumen. Distal portions slope downward about half the height of the concavity. Basals 5; AB, BC, DE, and EA pentagonal; CD usually hexagonal, being truncated for anal X, but may be pentagonal if anal X is not contacted. Proximal tips of basals in basal concavity; medial portions recurve and form basal plane of cup, and distal portions rise about half the height of the cup. Radials 5, epaulette-shaped, with proximal tips reaching basal plane of cup in some rays. Anal X highly variable; it may or may not separate C and D radials on outside of cup, and may or may not connect to distal end of CD basal.

Outer cup walls slope at about 45 degrees near cup base, the slope changing abruptly at about two-thirds the height of the cup, where cup walls are nearly vertical. Cup walls recurve inward near cup summit obscuring view of distal portions of radials from basal view of cup. Cup ornamented with large granules, coarse tubercles, ridges, and pustules. Fine granules are evenly distributed between coarse tubercles and ridges (Fig. 16a).

Radial articular facets plenary, level to sloping gently outward. Outer marginal ridge sharp, separated from transverse ridge by a narrow, deep outer marginal furrow. Transverse ridge only faintly denticulate; oblique ridge faint, with few denticles. Adjacent adsutural slopes steep, well-defined; lateral ridge is well defined but not sharp. Muscle areas broad, sloping inward to wide central pit that connects to a broad intermuscular notch by short, wide intermuscular furrow.

PBr1 short, somewhat protruded, followed by trapezoidal SBr1. SBr2 to SBr15 biserial where observed. Primibrachials and lower secundibrachials ornamented with nodes, ridges, pustules, and granules.

Remarks.—*Graffhamicrinus magnificus* appears to have been evolving toward forms with deeply recessed anal plates (Figs. 19g, i). This tendency has also been observed in a specimen from the Beil Limestone Member of the Lecompton Formation reported by Pabian and Strimple (1974a, pp. 270, 271).

The sample of *Graffhamicrinus magnificus* from the Stull Shale of Nebraska contains individuals that either eliminate (Figs. 19d–f, j–l) or resorb (Figs. 19g–i) the anal plate. Such a tendency, over a long time, is an important evolutionary trend of many crinoid lineages. Over a short time span, however, such a trend may be much less significant. We decline to relegate individuals with only a rudimentary anal plate or without an anal X plate to separate species or genera (e.g. *Paradelocrinus*), assuming that these few specimens represent a condition that occurred in a very short time span. If the tendency to eliminate the anal X plate continued over a very long time span, then the lineage should become stabilized, with a majority of the individual crinoids having lost the anal X plate. A small number of individual crinoids in the same lineage should show a tendency to retain primitive characteristics by retaining the anal X plate (Figs. 19a–c).

Three species of crinoids from the Stull Shale of Nebraska developed nodes on the lower parts of the arms: *Graffhamicrinus magnificus*, *G. decapodos* and *Delocrinus vulgatus*. This feature is possibly indicative of specific adaptive capabilities rather than of phylogeny.

Material Studied.—Hypotypes, UNSM 12518–UNSM 12525, from Ace Hill; UNSM 8024–UNSM 8044, all from Weeping Water, Nebraska; and UNSM 10492, from Melvern, Kansas.

Graffhamicrinus subcoronatus (Moore and Plummer), 1940

Figs. 7, 8, 9, 20a–f, 21a–c

Delocrinus subcoronatus Moore and Plummer, 1940, pp. 280–282; pl. 17, fig. 1.

Graffhamicrinus subcoronatus (Moore and Plummer) Pabian and Strimple, 1974a, p. 271, pl. 37, figs. 9–11; 1974, p. 15.

Description.—Cup basally impressed, low bowl. Infrabasals 5, pentagonal, confined to upper portion of narrow basal concavity. AB, BC, DE, and EA basals pentagonal with proximal one-third restricted to concavity, medial one-third forming basal plane of cup and distal one-third rising about half the cup height at about 60 degrees to the horizontal. CD basal usually truncated for

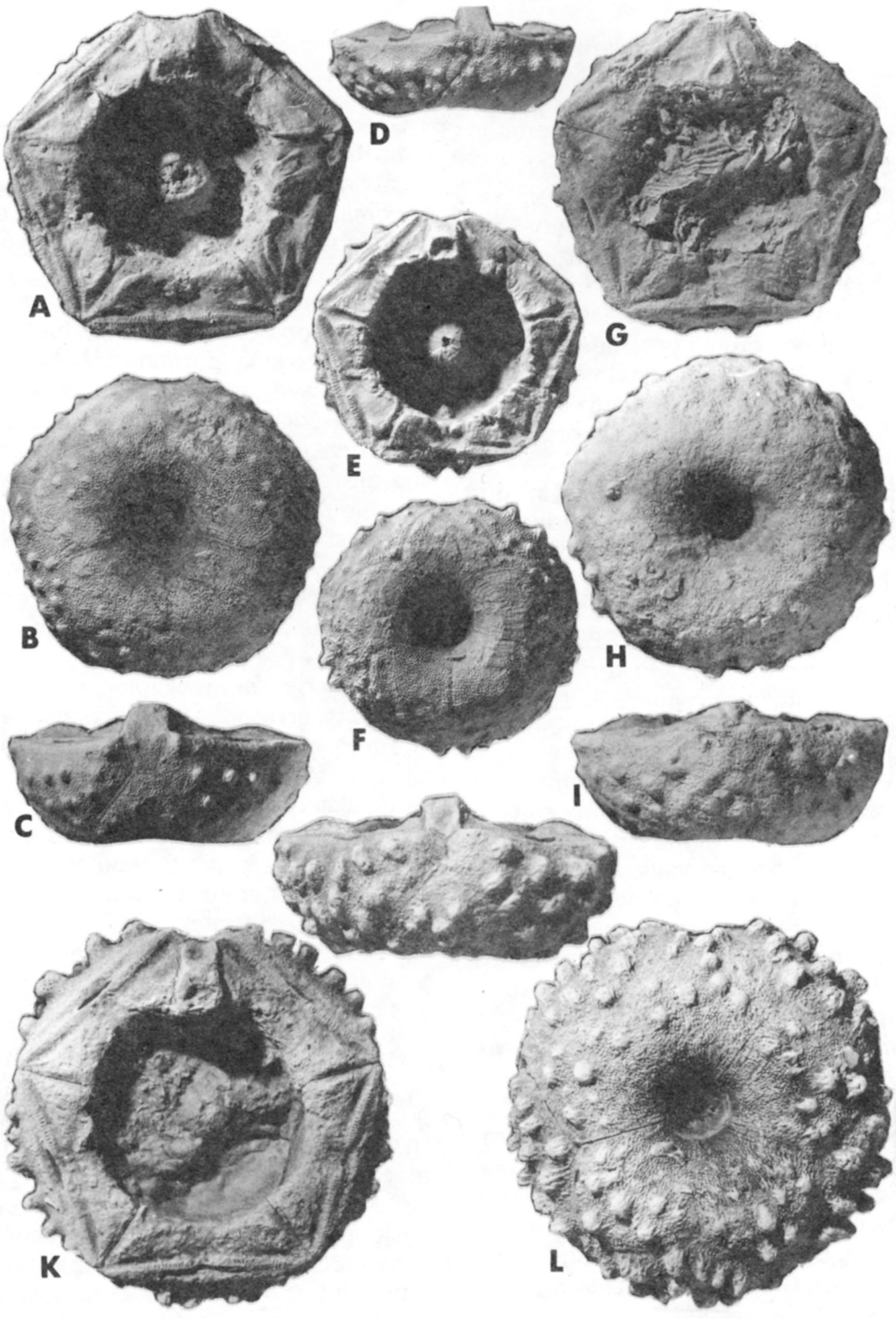

Fig. 19. *Graffhamicrinus magnificus* (Strimple). Developmental trends in disposition of anal X plate. A–C. Ultimate type A, summit, basal, and posterior views of hypotype, UNSM 8036, X3. D–F. Ultimate type A approaching ultimate type A(1), posterior, summit, and basal views of hypotype, UNSM 8032, X3. G–I. Symmetrical type, summit, basal and posterior views of hypotype, UNSM 8035, X2. J–L. Ultimate type A(1), posterior, summit, and basal views of hypotype, UNSM 8044, X3. Terminology after Strimple, 1960, pp. 247–253.

reception of 6-sided anal X plate. Anal X does not always contact CD basal on outer cup wall, but always intervenes between C and D radials in the samples studied.

Radial articular facets plenary, nearly flat lying. Outer marginal ridge not sharp; outer marginal furrow very narrow; transverse ridge very fine with few faint denticles; ligament pit is a prominent slot located midway along the transverse ridge; oblique ridge short, non-denticulate; lateral ridge faint but lateral slopes prominent. Muscle areas inflated laterally and slope steeply into a deep, half-round central pit that connects to a broad, V-shaped intermuscular notch by a short, deep intermuscular furrow.

Cup is ornamented with fine to medium, irregularly spaced granules, and the entire surface of the cup appears roughened. Sutures between plates indistinct to absent.

PBr1 long, axillary, spinose, and followed by trapezoidal SBr1 and biserial SBr2 to SBr30 where observed. Primibrachials and lower secundibrachials covered with fine granules. All secundibrachials have facets for reception of pinnules.

Remarks.—The most conspicuous difference between *Graffhamicrinus magnificus* and *G. subcoronatus* is the nature of the ornamentation. *G. subcoronatus* has a more shallow, funnel-like basal concavity, and much more poorly defined radial articulating facets. *G. magnificus* has a short, protruded primibrachial, whereas *G. subcoronatus* has a long, spinose primibrachial.

None of the specimens of *G. subcoronatus* from the Stull Shale of Nebraska show the tendency to eliminate the anal X plate by resorption as do some of the specimens of *G. magnificus* previously reported. In our samples, *G. subcoronatus* appears to have reduced the importance of the anal X plate only through elimination. This may possibly be interpreted as speciation ultimately produced by two divergent lineages from a common ancestor, *G. subcoronatus* having been the more conservative species.

Material Studied.—Hypotypes, UNSM 8045–UNSM 8058, UNSM 8075–UNSM 8077, all from Weeping Water, Nebraska; UNSM 12438–UNSM 12472, all from Ace Hill; UNSM 10493–UNSM 10494, both from Melvern, Kansas.

Graffhamicrinus sp.

Figs. 21d–f

Description.—Dorsal cup low, anteriorly flattened bowl with medium-wide basal concavity. Infrabasals 5, kite-shaped, confined to concavity; proximal half marked with columnar cicatrix and pentalobate lumen; distal ends nearly vertical. AB, BC, DE, and EA basals pentagonal, CD being truncated to receive anal X; all with parabolic cross sections and rising about half the height of the cup. Proximal portions of basals confined to basal concavity; midportions make up basal plane of cup. Radials 5, nearly touching basal plane; they curve upward at about 45 degrees proximally and are most expanded at about three-fourths their height, and recurve inward abruptly near the summit of the cup. C and D radials separated by narrow, wedge-like anal X plate, the distal portion of which is at a low angle relative to the radial plane and which extends far into the body cavity.

Radial articular facets plenary. Outer ligament and transverse ridges denticulate, separated by deep ligament pit furrow and distinct ligament pit. Lateral furrows deep; oblique ridges short, denticulate. Lateral ridges sharp; adsutural slope about 45 degrees. Muscle areas large, sloping inward to deep, sub-triangular central pit that connects to intermuscular notch by a short, wide intermuscular furrow.

Plates covered with regularly spaced, fine granules and randomly distributed, coarse nodes and pustules.

Remarks.—This specimen is unusual because of its striking resemblance to *Diphuicrinus*, the probable ancestor to *Graffhamicrinus*. The wide, shallow basal concavity, the sloping anal X that reaches into the cup body, and the cup outline are the most striking of the primitive features on this cup. Because only one such cup was found in over 80 *Graffhamicrinus* cups, it is thought to represent one of the described species in this genus rather than a separate entity. The cup cross section most closely resembles that of *Cathetocrinus stullensis*, but the ornamentation most closely resembles that of *G. magnificus*.

Material Studied.—Hypotype, UNSM 13316, from Ace Hill.

Family ERISOCRINIDAE Wachsmuth and Springer, 1886

Type Genus.—*Erisocrinus* Meek and Worthen, 1865a, p. 174.

Diagnosis.—Crown tall, cylindrical, with closely abutting, erect arms. Cup broadly truncate conical, with planate or faintly concave or convex base; five infrabasals not visible from side; proximal tips of radials well above basal plane of cup; single anal plate or none in CD interray. Arms 10, branching isotomously in all rays on first primibrachial. Stem transversely round, lacking cirri.

Occurrence.—Lower Pennsylvanian (Morrowan) -Lower Permian (Wolfcampian), U.S.A., (Illinois, Ohio, Iowa, Nebraska, Missouri, Kansas, Oklahoma, Texas, Nevada); Upper Carboniferous, China.

Genus ERISOCRINUS Meek and Worthen, 1865a

[=*Libratocrinus* Knapp, 1969; *Pontotocrinus* Knapp, 1969; *Parerisocrinus* Knapp, 1969].

Diagnosis.—Characters of family, anal mostly not visible from outside of cup; arms biserial.

Other Species Included.—*Erisocrinus elevatus* Moore and Plummer, 1940; *E. propinquus* Weller, 1909; *E. georgeae* Strimple and Watkins, 1969; *E. longwelli* Lane and Webster, 1966; *E. healdae* Pabian and Strimple, 1974a; *E. knoxvillensis* Strimple, 1975b.

Occurrence.—Lower Pennsylvanian (Morrowan)–Lower Permian (Wolfcampian), U.S.A., (Illinois, Iowa, Missouri, Nebraska, Kansas, Oklahoma, Texas, Nevada).

Erisocrinus typus Meek and Worthen, 1865a
Figs. 23a–f

Erisocrinus typus Meek and Worthen, 1865a, p. 174; 1873, p. 561, pl. 24, fig. 6; Strimple, 1938, p. 6, pl. 1, figs. 14–17, pl. 2, figs. 2–5; 1959, p. 120, pl. 1, figs. 14–17; 1960, p. 155, fig. 2d; Moore and Plummer, 1940, p. 152, pl. 2, fig. 5; pl. 4, figs. 4, 5, pl. 19, fig. 4, text-fig. 24, 25; Moore and Laudon (in Shimer and Shrock) 1944, p. 173, pl. 62, figs. 26, 27, pl. 65, fig. 28; Cuenot, 1948, p. 62; Moore, 1950, fig. 40; Tischler, 1963, p. 1066, figs. 6a, b; Arendt and Hecker, 1964, p. 90; Knapp, 1969, p. 359, text-figs. 14a, b; Pabian and Strimple, 1974b, p. 15, figs. 6, 2,3; 1980a, p. 13, pl. 4, figs. 1–3.

Phialocrinus pelvis Meek and Worthen, 1865a, p. 350.

Erisocrinus nebrascensis Meek and Worthen, 1865b, p. 174, p. 350.

Description.—Cup medium, truncate bowl. Infrabasals 5, flat-lying, forming sub-stellate infrabasal disk with round, crenulate columnar cicatrix with pentalobate lumen. Basals 5, with proximal portions in basal plane of cup, medial portions curving upward, and distal portions rising about half the height of the cup. Radials 5, proximal tips not reaching basal plane, and rising at about a 70 degree angle to the base. C and D radials separated by rudimentary anal X plate on inside walls of cup only.

Radial articular facets plenary, narrow. Outer marginal ridge and weakly denticulate transverse ridge separated by outer ligament furrow and ligament pit. Adsutural slopes short, forming shallow furrow with adjacent slope. Muscle areas not well-defined, sloping inward to faint central pit that connects to intermuscular notch by a short furrow.

Remarks.—This species represents a conservative lineage of long-range, Missourian through Virgilian. This lineage appears to have several closely related species, including *Erisocrinus propinquus* Weller and *E. elevatus* Moore and Plummer, of which it is likely that *E. typus* was antecedent.

Material Studied.—Hypotypes, SUI 37700a–c; UNSM 11843–UNSM 11845; USNM 247907–USNM 247910, all from Melvern, Kansas.

Erisocrinus sp. cf. *E. terminalis* Strimple, 1962c
Figs. 23g–i

Erisocrinus terminalis Strimple, 1962c, p. 13, pl. 9, figs. 1–4.

Libratocrinus terminals (Strimple) Knapp, 1969, p. 354. Pabian and Strimple, 1974a, p. 258.

Description.—Cup low to medium bowl. Infrabasals 5, forming stellate disk in a very shallow concavity. Columnar cicatrix round, crenulated, with pentalobate lumen. Proximal tips of 5 basals in shallow concavity, midportions form basal plane of cup, and distal halves curve upward in a parabolic cross section about half the cup height. Radials 5, with tips not reaching basal plane of cup; they rise upward in a broad, circular arc. C and D radials separated by rudimentary anal X plate. Cup surface smooth.

Radial articular facets plenary, wide with outer marginal and transverse ridges separated by narrow, deep outer marginal furrow and ligament pit. Adsutural slopes wide, forming broad furrow with adjacent slope. Muscle areas not well defined and sloping inward to shallow central pit. Arms not known.

Remarks.—At least one lineage of *Erisocrinus* appears to have evolved shallow cups. Knapp (1969, p. 354) erected *Libratocrinus* to receive these forms and stated that the radials touching the infrabasals indicated a close relationship to *Protencrinus*. It may be that the relationship of radials touching the infrabasals has a much closer bearing to the symmetry planes of the crinoid than to its ancestry or relationships. (See Lane 1967, pp. 14–16).

An alternative explanation for the radial plates touching the infrabasals may lie in the fact that many erisocrinids in older Missourian age rocks have collapsed basal areas. Such specimens have been collected from Iowa, Nebraska, and Oklahoma. By shortening basal sutures, these crinoids may have stabilized the weak basal areas.

Material Studied.—Hypotype, SUI 37704, from Melvern, Kansas.

Superfamily TEXACRINACEA Strimple, 1961a
Family CYMBIOCRINIDAE Strimple and Watkins, 1969

Cymbiocrinidae Strimple and Watkins, 1969, p. 188; Moore and Strimple, 1973, p. 77.

Type Genus.—*Cymbiocrinus* Kirk, 1944, p. 233.

Diagnosis.—Crown medium height, with 5 or 10 uniserial, erect arms. Cup broadly truncate cone or bowl. Base flat or with concavity. Infrabasals not visible from side. Radial articular facets equal in width to summit of these plates. Single anal (?radianal) plate in cup. Anal sac cylindrical, composed of few longitudinal rows of polygonal plates. Arms uniserial, well rounded, pinnulate in 10-armed genera invariably branching isotomously on PBr2. Stem transversely round or pentagonal with long, slender cirri directed obliquely upward.

Other Genera Included.—*Aenigmocrinus* Strimple, 1973a; *Aesiocrinus* Miller and Gurley, 1890 [=*Pentadelocrinus* Strimple, 1939b]; *Allosocrinus* Strimple, 1949a; *Lecobasicrinus* Strimple and Watkins, 1969; *Proallosocrinus* Moore and Strimple, 1973; *Oklahomacrinus* Moore, 1939; *Adacrinus* Pabian and Strimple, n. g.; *Sardinocrinus* Pabian and Strimple, n. g.; *Kansacrinus* Pabian and Strimple, n. g.

Occurrence.—Upper Mississippian (Genevievian)–Lower Permian (Wolfcampian), U.S.A. (Illinois, Alabama, Missouri, Iowa, Nebraska, Kansas, Texas, Oklahoma, Nevada).

Genus OKLAHOMACRINUS Moore, 1939

Type Species.—*Oklahomacrinus supinus* Moore, 1939, pp. 258–261.

Diagnosis.—Cup low, pentagonal; infrabasals 5, flat; basals 5, bulbous, forming basal plane; radials 5, nearly flat-lying; ?radianal elongated; radial articular facets plenary, outer ligament area nearly vertical. PBr1 a parallelogram, PBr2 triangular, axillary; arms 10, pendent, or long, uniserial.

Other Species Included.—*Oklahomacrinus frostae* Strimple and Watkins, 1969; *O. spicatulus* Strimple and Watkins, 1969. *O. ohioensis* Burke, 1966.

Range.—Middle Pennsylvanian (Desmoinesian)–Upper Pennsylvanian (Virgilian), U.S.A. (Oklahoma, Kansas, Nebraska, Texas, Ohio).

Oklahomacrinus supinus Moore, 1939
Figs. 20g-h

Oklahomacrinus supinus Moore, 1939; pp. 258–261, pl. IX, figs. 5a–d; Moore & Laudon in Shimer and Shrock, 1944, p. 167, pl. 56, fig. 24, pl. 62, fig. 19.

Description.—Dorsal cup low, discoid. Infrabasals 5, kite-shaped, flat lying elements with only proximal tips covered by pentagonal, crenulated columnar cicatrix with round lumen. Basals 5, bulbous, shield-shaped, flat-lying with CD truncated for reception of anal (?radianal) plate. Radials 5, tapered pentagons, somewhat bulbous, nearly flat-lying. The basal plane of the cup is situated on the bulbous areas near the midportions of the basals and proximal portions of the radials. Sutures between plates are sharply depressed at junctions between adjacent basals and intervening radials or between adjacent radials and intervening basals. Cup plates smooth or with very few fine granules. Sutures between plates sharply impressed.

Radial articular facets peneplenary; outer facetal area nearly vertical, muscle areas nearly flat-lying. Outer marginal ridge sharp, well-defined. Outer marginal furrow deep and wide. Ligament pit prominent; transverse ridge sharp, non-denticulate. Lateral ridge sharp and lateral slope nearly vertical. Muscle areas flat and only a very shallow central pit can be seen.

PBr1 trapezoidal; PBr2 triangular, axillary. SBr1 trapezoidal; succeeding secundibrachials subtriangular.

Remarks.—Moore (1939, pp. 258–261) described *Oklahomacrinus supinus* from the Brownville Limestone Member of the Kanawa (=Wood Siding) Formation of the Virgil Series that is exposed near Strohm in Osage County, Oklahoma. The known range for this species is from the Stull Shale Member of the Kanwaka Formation of the Shawnee Group in the Virgil Series through the Brownville Limestone Member of the Kanawa Formation. Its geographic distribution is northeastern Oklahoma and southeastern Nebraska.

Material Studied.—Holotype specimen, USNM 141106, Osage County, Oklahoma; hypotypes, UNSM 8060 and UNSM 8061, both from Weeping Water, Nebraska.

Genus ADACRINUS Pabian and Strimple, n. g.

Type Species.—*Oklahomacrinus loeblichi* Moore, 1939, pp. 261–265.

Diagnosis.—Cup low, pentagonal; infrabasals 5, flat to down-flared; basals 5; basals and infrabasals confined to basal concavity; radial articular facets plenary; outer ligament area nearly vertical. PBr1 parallelogram; PBr2 triangular, axillary. Arms 10, short, uniserial.

Other Species Included.—*Oklahomacrinus stevensi* Moore, 1939; *O. bowsheri* Moore, 1939; *O. ellesmerensis* Strimple and Nassichuk, 1974; *O. canyonensis* Strimple and Nassichuk, 1974.

Remarks.—*Adacrinus* is derived from Ada, Oklahoma, from where the type species was collected. It differs from *Oklahomacrinus* in the nature of both the basal concavity and the basal plane of the cup. In *Oklahomacrinus*, the infrabasals and proximal parts of the basals form the basal concavity and the midportions of the basals form the basal plane of the cup. In *Adacrinus*, the infrabasals and basals are both confined to the basal concavity and the basal plane of the cup is formed by the protuberant radials.

Range.—Middle Pennsylvanian (Desmoinesian) -Upper Pennsylvanian (Virgilian), U.S.A., (Oklahoma); Canada, (Ellesmere Island).

Material Studied.—Holotype of type species, USNM 141107; holotype of *A. stevensi*, USNM 141109; holotype of *A. bowsheri*, USNM 141108; holotype of *A. canyonensis*, GSC 33874; paratype of *A. canyonensis*, GSC 33875; holotype of *A. ellesmerensis*, GSC 33876.

Genus SARDINOCRINUS
Pabian and Strimple, n. g.

Type Species.—*Oklahomacrinus abruptus* Strimple, 1961a

Diagnosis.—Infrabasals 5, confined to narrow, constricted basal concavity. Basals 5, with proximal parts in basal concavity, midportions forming basal plane of cup together with proximal parts of 5 tapered pentagonal radials. Anal X barrel-shaped; cup low. PBr1 trapezoidal, PBr2 axillary. Arms 10, uniserial, long. Stem round, cirriferous.

Other Species Included.—None.

Remarks.—*Sardinocrinus* is characterized by its very deep, narrow, and constricted basal

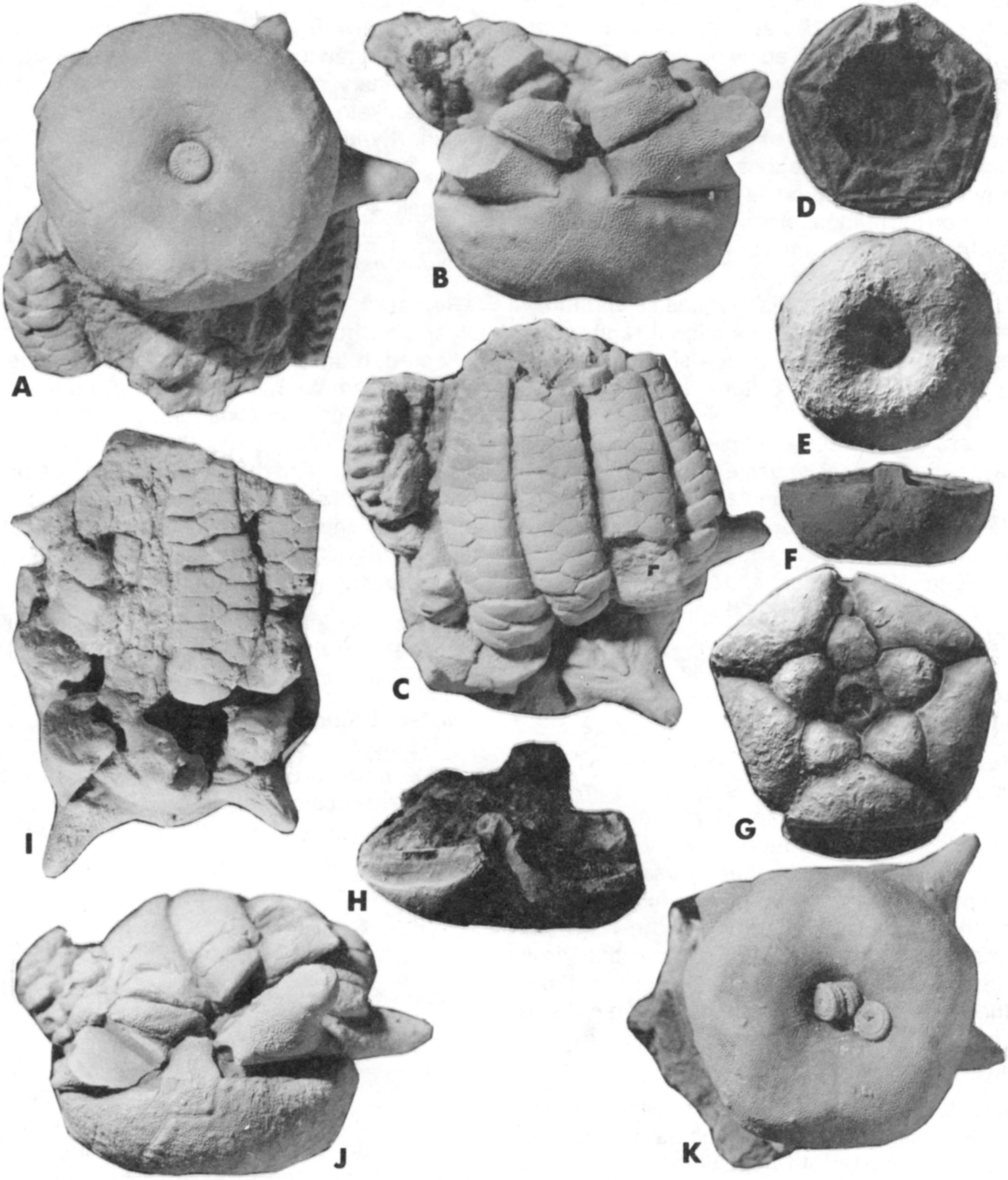

Fig. 20. A–F. *Graffhamicrinus subcoronatus* (Moore and Plummer). A–C. Partial crown, basal, posterior, and summit views, hypotype UNSM 12472, from Ace Hill, X2. D–F. Summit, basal, and posterior views of dorsal cup, hypotype UNSM 8017, from Weeping Water, X2. G, H. *Oklahomacrinus supinus* Moore, basal and posterior views, hypotype, UNSM 8060, from Weeping Water, X2. I–K. *Cathetocrinus stullensis* (Strimple), summit, posterior, and basal views of hypotype, UNSM 12515, from Ace Hill, X2.

concavity, which suggests closer affinity to *Oklahomacrinus* than to *Adacrinus.*

A second species of *Sardinocrinus* has been collected from the Winterset Limestone Member of the Dennis Formation in the Kansas City Group of the Missouri Series; it will be described in a subsequent study of the crinoids of the Winterset Limestone.

Range.—Middle Pennsylvanian (Desmoinesian)–Upper Pennsylvanian (Virgilian), U.S.A., (Nebraska, Oklahoma).

Material Studied.—Holotype of type species, OU 4045; paratype of type species, OU 4046.

Genus KANSACRINUS Pabian and Strimple, n. g.

Type Species.—*Oklahomacrinus cirriferous* Strimple, 1963.

Diagnosis.—Cup discoid. Infrabasals 5, forming high dome inside of cup and confined to a broad concavity outside. Basals 5, confined to basal concavity; radials 5, with basal plane of cup confluent with their midportions. Anal X elongate; may be enwrapped by C and D radials. Stem round, with cirri. Outer ligament area may be on underside of radials when cup viewed from above. Arms unknown.

Other Species Included.—*Oklahomacrinus discus* Strimple, 1947; *O. regularis* Strimple, 1951c.

Remarks.—*Kansacrinus* is characterized by its lozenge-like cup with a high, interior infrabasal dome. Cup morphology suggests its closest affinities are probably *Oklahomacrinus*.

Material Studied.—Holotype of type species, USNM 134651; holotype of *K. discus*, USNM S-4733; holotype of *K. regularis*, USNM S-4724.

***Kansacrinus discus* (Strimple), 1947**
Figs. 15k, 26i–k

Oklahomacrinus discus Strimple, 1947, p. 6, pl. 2, fig. 2; Burke, 1966, p. 466, fig. 3.

Remarks.—This species provides an excellent example of the anal plate being enwrapped by the C and D radials. Such enwrapping of the anal plate by the C and D radials may provide an example of apparent but not real resorption of the anal X (?radianal) plate (see Fig. 15K).

Family AMPELOCRINIDAE Kirk, 1942

Type Genus.—*Ampelocrinus* Kirk, 1942, p. 23.

Diagnosis.—Cup dicyclic; infrabasals 5, visible in side view of cup; one anal plate. Radial articular facets short. Arms usually branch on PBr2; pinnule bearing on alternate sides except for syzygial pairs. Anal tube moderate, recurved in older forms, straight in younger genera. Stem sub-pentagonal, round, or pentalobate. (Modified after Strimple and Moore, 1971a, p. 28).

Range.—Mississippian–Permian; U.S.A., U.S.S.R., Scotland.

Other genera included.—*Armenocrinus* Strimple and Horowitz, 1973 (Lower Mississippian–Upper Mississippian); *Arroyocrinus* Lane and Webster, 1966 (Lower Permian); *Chlidonocrinus* Strimple and Watkins, 1969 (Upper Mississippian–Upper Pennsylvanian); *Halogetocrinus* Strimple and Moore, 1971a (Middle Pennsylvania –Upper Pennsylvanian); *Moundocrinus* Strimple, 1939b (Upper Pennsylvanian); *Polusocrinus* Strimple 1951c (Upper Pennsylvanian–Lower Permian); *Spheniscocrinus* Wanner 1937 (Upper Permian).

Genus MOUNDOCRINUS Strimple, 1939b

Type Species.—*Moundocrinus osagensis* Strimple, 1939b.

Diagnosis.—Dorsal cup medium bowl-shaped, with broadly truncate, flattened, or mildly concave base; cup plates smooth; sutures unimpressed. Infrabasals 5, confined to basal area, not visible in side view of cup. Radial articular facets short, not extended beyond normal thickness of plates. Anal X large, usually not extending appreciably above cup summit, and followed in series by a single tube plate. Arms 10, uniserial, branching on PBr2, unless fused with PBr1. Proximal columnals pentagonal.

Other Species Included.—*Moundocrinus coa-*

lensis Strimple, 1975a; *Aesiocrinus luxuris* Strimple, 1949a.

Range.—Lower Pennsylvanian (Atokan)–Upper Pennsylvanian (Missourian); Oklahoma, Illinois, Nebraska.

Moundocrinus sp.

Figs. 16f, g

Description.—*Moundocrinus* is represented here by only an immature, slightly damaged, partial crown. Infrabasals 5, flat lying, with proximal half covered by a round, crenulated columnar cicatrix. AB, BC, DE, and EA basals pentagonal; CD basal rectangular, being truncated for reception of large, hexagonal, anal X plate. Basals sharply up-flared, giving cup a hemispherical cross section, with distal tips rising about half the cup height. Radials 5, large, pentagonal. Plates smooth; sutures indistinct.

Radial articular facets nearly flat lying; outer marginal ridges faint; outer ligament furrow narrow; ligament pit deep and prominent. Pbr1 appears to be non-axillary.

Material Studied.—Hypotype, UNSM 8059, Weeping Water, Nebraska.

Superfamily PIRASOCRINACEA Moore and Strimple, 1973

Type Genus.—*Pirasocrinus* Moore and Plummer, 1940, p. 370.

Diagnosis.—Crown pyriform; cup very low bowl-shaped, with mostly deep basal concavity and rounded, steep-sided, incurved to rim; radial articular facets peneplenary and declivate; interradial notches between arm facets; normally 3 anal plates in cup; mushroom-shaped anal sac taller than arms, and has girdle of horizontal sac spines around summit platform. (Modified after Moore and Strimple, 1973).

Remarks.—As presently defined, the Pirasocrinacea includes the following families: Pirasocrinidae Moore and Laudon, 1943; Adinocrinidae Strimple, 1961a.

Range.—Lower Mississippian (Kinderhookian)–Lower Permian (Wolfcampian); U.S.A., U.S.S.R.

Family PIRASOCRINIDAE Moore and Laudon, 1943

Type Genus.—*Pirasocrinus* Moore and Laudon, 1943, p. 370.

Diagnosis.—Crown tall, relatively slender, widest at height of secundaxils, isotomous branching of arms at uniform heights in each ray, which, with bulbous nature of axillary brachials, provides pagoda-like appearance. Cup saucer-like with deep basal concavity; radial articular facets peneplenary and declivate; three anals in cup. Arms recti-uniserial, exceptionally biserial. Anal sac mushroom shaped, with spine-girdled summit platform slightly above arm tips. Stem circular in section.

Genera.—*Pirasocrinus* Moore and Plummer, 1940; *Aatocrinus* Moore and Plummer, 1940; *Affinocrinus* Knapp, 1969. *Eirmocrinus* Strimple and Watkins, 1969; *Exterocrinus* Knapp, 1969; *Lasanocrinus* Moore and Plummer, 1940; *Metaffinocrinus* Knapp, 1969; *Metaperimestocrinus* Strimple, 1961a; *Metutharocrinus* Moore and Strimple, 1973; *Perimestocrinus* Moore and Plummer, 1938; *Platyfundocrinus* Knapp, 1969; *Plaxocrinus* Moore and Plummer, 1938; *Polygonocrinus* Strimple, 1961a; *Psilocrinus* Knapp, 1969; *Retusocrinus* Knapp, 1969; *Schedexocrinus* Strimple, 1961a; *Sciadiocrinus* Moore and Plummer, 1938; *Separocrinus* Knapp, 1969; *Simocrinus* Knapp, 1969; *Stenopecrinus* Strimple, 1961a; *Triceracrinus* Bramlette, 1943; *Utharocrinus* Moore and Plummer, 1938; *Vertigocrinus* Knapp, 1969; *Zeusocrinus* Strimple, 1961a.

Range.—Upper Mississippian (Chesteran)–Lower Permian (Wolfcampian); U.S.A., U.S.S.R.

Genus PLAXOCRINUS Moore and Plummer, 1938

Type Species.—*Hydreionocrinus crassidiscus* Miller and Gurley, 1890.

Diagnosis.—Dorsal cup round to sub-pentagonal, with broad, shallow basal concavity and wide interradial notches. Infrabasals 5, with proximal tips down-flared and covered by crenulated columnar cicatrix with pentalobate lumen. Basals 5, with proximal tips included in concavity of cup, and distal portions flaring upwards and being readily visible in side view of cup. Radials

5, wide, slightly tumid, with proximal tips included in basal plane. Posterior interradius narrow, the radianal is in direct posterior position, and anal X directly above it. Radial articular facets peneplenary, outward sloping. Arms uniserial.

Other Species Included.—*Hydreionocrinus kansasensis* Weller, 1898; *Zeacrinus discus* Meek and Worthen, 1860; ?*Plaxocrinus aplatus* Moore and Plummer, 1940; *P. orthodoxus* Moore, 1939; *P. strigosus* Moore and Plummer, 1938; *P. virginarius* Moore, 1939; *P. oeconomicus* Strimple, 1951a; *P. normalis* Strimple, 1961a; *P. octarius* Strimple, 1961a; *P. macrospiniferus* Pabian and Strimple, 1974b; *P. piutae* Lane and Webster, 1966; *P. beggsi* Strimple, 1961a; *P. brasilensis* Lane, 1964a; *P. puteus* Strimple, 1949b.

Plaxocrinus sp. cf. *P. crassidiscus* (Miller and Gurley), 1890

Figs. 21k–l, 26f–h

Hydreionocrinus crassidiscus Miller and Gurley, 1890, p. 43, pl. 6, figs. 18, 19.

Plaxocrinus crassidiscus (Miller and Gurley), 1890; Moore and Plummer, 1938, p. 277, text-fig. 26; Moore and Laudon (in Shimer and Shrock), 1944, p. 163, pl. 62, fig. 7, pl. 63, fig. 7; Pabian and Strimple, 1974a, p. 5; 1980a, p. 17, pl. 6, figs. 1–4; 1980b, p. 179, figs. 7g–k.

Description.—Dorsal cup nearly flat with slightly tumid plates separated by shallow sutures and having flat to very shallow base. Infrabasals 5, kiteshaped in nearly flat lying circlet with center covered by round, crenulated columnar cicatrix with round lumen. Basals 5, with proximal fourth included in concavity; cup rests on narrow basal plane; distal ends of basals rise gently upward. AB, BC, DE, and EA basals may be pentagonal; CD modified to an irregular heptagon to accommodate irregular, rhomboidal radianal to the right and anal X plate to the above left, or CD may be pentagonal in cases where anal X has lost contact with it. Radials 5, nearly flat-lying proximally, but curving sharply upward medially so that distal ends are nearly vertical. A, B, C, and E are epaulette-shaped; D is trapezoidal. Radial sutures marked by notches at top of cup. Radianal may have 6 or 7 sides and be bound by BC and CD basals below; C radial, anal X and right tube plate above. Anal X with 6 or 7 sides and bound by CD basal below, C radial, radianal, and right tube plates laterally. Right tube plate above.

Outer marginal ridge sharp and outer ligament furrow deep. Outer ligament ridge thin, sharp. Ligament pit furrow very shallow, leading to very deep ligament pit. Facetal area geniculates sharply inward at well-defined, slightly denticulate transverse ridge. Lateral furrow well-impressed, but oblique ridge is faint and leads to broad muscle area that indistinctly merges with a subtriangular central pit that connects to a deep intermuscular notch by a narrow intermuscular furrow. Lateral ridge low, leading to an almost exaggerated lateral lobe. Adsutural slope very low.

Cup surface smooth or finely granular; sutures well-defined but not strongly impressed.

Remarks.—*Plaxocrinus crassidiscus* may be confused with 4 other species: *P. orthodoxus* Moore, 1939; *P. virginarius* Moore, 1939; *P. normalis* Strimple, 1961a, and *P. beggsi* Strimple, 1961a. *P. virginarius*, from the Brownville Limestone Member of the Kanawa Formation of Late Virgilian age, has a very deep cup in relation to its diameter. *P. orthodoxus*, also from the Brownville Limestone of Oklahoma, has a very shallow cup in relation to its diameter and most of the length of its basals is involved in the basal plane of the cup. *P. normalis* and *P. beggsi*, both from the Desmoinesian age Holdenville Formation of Oklahoma, have a slightly concave infrabasal disk. *P. crassidiscus* may be an intermediate member of a *P. normalis* - *P. beggsi* - *P. crassidiscus* - *P. orthodoxus* lineage.

Material Studied.—Hypotypes, UNSM 16500, Ace Hill; UNSM 12431, Weeping Water; UNSM 23334, Melvern, Kansas.

Genus VERTIGOCRINUS Knapp, 1969

Type Species.—*Perimestocrinus subtilus* Moore, 1939.

Diagnosis.—(After Knapp, 1969, p. 378). Basal concavity narrow and distinct; notches between facets narrow, giving the cup a hexagonal outline; sutures impressed.

Other Species Included.—*Plaxocrinus politus* Moore, 1939; *P. parilis* Moore and Plummer, 1938;

P. calyculus Moore and Plummer, 1940; *P. gloukosensis* Strimple, 1951b.

Remarks.—Although several species of *Vertigocrinus* are abundant throughout much of the Pennsylvanian of Nebraska, only one representative of this genus, *V. gloukosensis*, is known from the Stull Shale of Nebraska. The specimens were all collected at Weeping Water. This distribution may reflect no more than collecting bias since there appear to have been no ecological, lithological, or sedimentological factors that would have affected the distribution of *Vertigocrinus*.

Range.—Middle Pennsylvanian (Atokan)–Lower Permian (Wolfcampian); U.S.A., (Nebraska, Iowa, Illinois, Ohio, Kansas, Missouri, Oklahoma, Arkansas, Texas, Nevada).

Vertigocrinus gloukosensis (Strimple), 1951b
Figs. 22g–i

Plaxocrinus gloukosensis Strimple, 1951b, p. 374, pl. 57, figs. 1–6; Moore and Strimple, 1973, p. 61, pl. 5, figs. 8, 9; 1974a, p. 283, pl. 36, figs. 4, 5; Pabian and Strimple, 1974a, pp. 283–284, figs. 11, 8, 9, 12, 6, 7; 1974b, p. 38, figs. 17, 3, 5.

Plaxocrinus sp. cf. *P. gloukosensis* Strimple, 1971a, p. 999, pl. 123, fig. 4.

Vertigocrinus gloukosensis (Strimple) Knapp, 1969, p. 378. Pabian and Strimple, 1980a, p. 17, text-fig. 2e.

Description.—Infrabasals 5, kite-shaped, nearly flat-lying, and restricted to broad, shallow concavity; proximal tips covered with round, crenulated columnar cicatrix with round lumen. Basals 5, AB, BC, CD, and EA basals shield shaped; DE an irregular hexagon. Radials 5, A, B, C, and E tapered pentagons; D trapezoidal to accommodate anal plates. Basal plane of cup confluent with medial portion of basals and proximal tips of radials. Radials curve upward uniformly, giving cup sides a quarter-round appearance in cross section. Anal X and right tube plates 6-sided.

Radial articular facets peneplenary; outer portions nearly vertical whereas muscle areas slope outward at about 45 degrees. Outer marginal ridge sharp; outer marginal furrow narrow, deep; ligament pit prominent. Transverse ridge faint, denticulate. Central pit broad, poorly defined. Intermuscular notch broad.

Remarks.—Four anal plates are preserved in a juvenile specimen, UNSM 16498. The radianal is irregular and 6-sided, touching the CD and DE basals below and the C and D radials above. Anal X and right tube plates are both 6 sided, and the small tube plate above has 4 sides.

Material Studied.—Hypotypes, UNSM 16498, UNSM 16400, both from Weeping Water.

Genus SCIADIOCRINUS
Moore and Plummer, 1938

Type Species.—*Zeacrinus* (*Hydreionocrinus*) *acanthophorus* Meek and Worthen, 1860.

Diagnosis.—Dorsal cup flat with deep, broad basal concavity which includes proximal tips of radials. Radials bulging and radial articular facets slope steeply outward.

Other Species Included.—*Sciadiocrinus crassacanthus* Moore and Plummer, 1939; *S. disculus* Moore and Plummer, 1940; *S. harrisae* Moore and Plummer, 1940; *Plaxocrinus obesus* Moore and Plummer, 1940; *Eupachycrinus platybasis* White, 1876; *Schistocrinus confertus* Moore and Plummer, 1940; *S. planatus* Moore and Plummer, 1940; *S. parvus* Moore and Plummer, 1940; *S. llanoensis* Strimple and Watkins, 1969; *Pirasocrinus invaginatus* Strimple, 1951a; *S. humilis* Strimple, 1951b.

Range.—Lower Pennsylvanian (Morrowan)–Upper Pennsylvanian (Virgilian); U.S.A.; (Texas, Oklahoma, Kansas, Nebraska, Iowa, Illinois, Utah).

Sciadiocrinus humilis Strimple, 1951b
Figs. 22a–c

Sciadiocrinus humilis Strimple, 1951b, p. 373, pl. 56, figs. 11–14; Knapp, 1969, p. 378; Pabian and Strimple, 1974a, p. 284, pl. 35, figs. 13–15; Pabian and Strimple, 1980a, p. 18, pl. 6, figs. 10–12.

Description.—Basal concavity broad, deep, including infrabasals, basals, and proximal tips of radials. Basal plane of cup on medial parts of radials. Infrabasals 5, confined to upper portion of concavity, with deeply impressed and crenulated, round columnar cicatrix with pentalobate lumen. Distal ends of infrabasals slope downward at about 45 degrees. Basals 5, meeting infrabasals with a sharp genuflection at junction causing the latter to slope downward at about 75 degrees. Basals curve uniformly and distal tips are nearly horizontal but not in basal plane of cup. A, B, C, and E radials tapered pentagons; D radial may be modified to either a hexagon or trapezoid, depending on position of radianal. Anal plates 3, in narrow posterior interradius. Radianal long, narrow, and may or may not touch DE basal. When touching DE basal, the D radial is trapezoidal; when not touching, D radial is hexagonal. Radianal followed by anal X and right tube plates.

Radial articular facets peneplenary with outer portions situated beneath dorsal side of cup and sloping downward and inward and muscle areas located dorsally and sloping downward and outward at about 45 degrees. Outer marginal ridge very sharp; outer marginal furrow narrow. Ligament pit deep and long and not visible in dorsal view of cup. Transverse ridge broad, with few denticles. Muscle areas triangular, sloping into broad, shallow, poorly defined central pit that connects to a large intermuscular notch by a short furrow.

Remarks.—*Sciadiocrinus humilis* shows a strong tendency to eliminate the radianal plate. UNSM 12529 has a "normal type" anal structure whereas UNSM 8062 shows an "extreme type A" anal structure, as defined by Strimple (1960, pp. 247–253).

This species is well distributed throughout the Virgilian strata of the midcontinent United States. It has been found in the Stull Shale of Nebraska and three specimens were collected from the Stull Shale at Melvern, Kansas. The Range Zone of *S. humilis* may well prove to be the Lecompton Megacyclothem (Schrott, 1966), or from the base of the Stull Shale in Nebraska through the top of the Ost Limestone.

Material Studied.—Hypotypes, SUI 37701, Melvern, Kansas; UNSM 8062, Weeping Water, Nebraska; and UNSM 12529, UNSM 12530, Ace Hill.

Sciadiocrinus sp. cf. *S. disculus* Moore and Plummer, 1940

Figs. 27b–d

Sciadiocrinus disculus Moore and Plummer, 1940, pp. 230–232, pl. 10, fig. 5, text-fig. 51; Moore and Laudon in Shimer and Shrock, 1944, p. 165, pl. 64, fig. 7.

Description—Dorsal cup low, discoid, with broad, shallow basal concavity. Infrabasal disk composed of 5 kite-shaped plates, the proximal portions of which are confined to a round, crenulated columnar cicatrix with a pentalobate lumen. Basals 5; AB, BC, EA pentagonal; CD and DE modified to hexagons to accommodate radianal and anal X plates; proximal portions confined to basal concavity and medial portions forming basal plane of cup together with proximal tips of radials; distal tips only in outer cup wall. Radials 5, epaulette shaped, rising upward in nearly circular cross section for about half the cup height, and terminating abruptly at radial facets, giving the cup a nearly pentagonal outline. C and D radials separated by anal X plate and right tube plate.

Radial articular facets plenary. Outer marginal ridge sharp, well defined, and separated from transverse ridge by a narrow ligament pit furrow and deep ligament pit. Transverse ridge denticulate. Lateral ridges sharp, forming lateral slope and well defined adsutural slope. Muscle area slopes gently into faintly defined central pit that connects to wide intermuscular notch by a faint furrow. Arms not known.

Remarks.—This species has been found in the Merriam Limestone Member of the Graford Formation in the Canyon Group of the Missourian Series in the Upper Pennsylvanian, exposed in Palo Pinto County, Texas. It is also known from the Desmoinesian age Mineral Wells Formation of the Strawn Group exposed in McCulloch County, Texas. Both of the specimens studied here were found at Melvern, Kansas. The very long range of this species suggests that it is of limited value as an index fossil.

Material Studied.—Hypotypes, UNSM 22236 and UNSM 22237, both from Melvern, Kansas.

Genus PERIMESTOCRINUS Moore and Plummer, 1938

Type Species.—*Hydreionocrinus nodulifer* Miller and Gurley, 1894.

Diagnosis.—(After Moore and Strimple, 1973, p. 76). Cup moderately deep, crateriform with subvertical upper sides curved slightly inward at summit; base distinctly and somewhat narrowly concave, radial articular facets peneplenary, with well marked interradial notches, gently to rather strongly declivate; three anal plates in relatively wide posterior interray. Anal sac unknown. Arms recti-uniserial, branching isotomously on primibrachial one in all rays. Stem transversely round.

Remarks.—There appear to be three closely related, or at least three morphologically similar genera, of pirasocrinids in the Virgilian strata of the North American midcontinent. These are *Perimestocrinus*, *Utharocrinus*, and *Tricerarcrinus*.

Perimestocrinus was proposed by Moore and Plummer (1938, p. 281), with *Hydreionocrinus nodulifer* Miller and Gurley designated as type species. *P. pumilis* and *P. teneris* were assigned to this genus in the same paper. Strimple (1950b, p. 571) placed *Triceracrinus* in synonymy with *Utharocrinus* but expressed dissatisfaction with the latter genus. Strimple (1961a, p. 20) proposed that species of *Utharocrinus* or *Triceracrinus* younger than Morrowan age be assigned to *Perimestocrinus*. Forms that had already been assigned to *Perimestocrinus* were to remain in that genus unless they were known to have spinose protrusions of axillary brachials. This restriction required the removal from *Perimestocrinus* of all species for which arms were known. Thus, Strimple (1961a, pp. 23, 24) emended the generic concept of *Perimestocrinus* to include 20 species. Strimple's (1961a) definition of *Perimestocrinus*, which included species of *Triceracrinus* and *Utharocrinus*, was based on geologic time definitions rather than on any clear-cut phyletic relationships. Although a generic range-zone may delineate a time unit, it is not sound practice to define a genus on the basis of a stratigraphic or a time unit.

Knapp (1969, p. 379) restricted *Perimestocrinus* to those forms with the characters of *Hydreinoncrinus nodulifer* Miller and Gurley. This action resulted in the various species of *Perimestocrinus* being assigned to *Triceracrinus*, *Stenopecrinus*, *Aatocrinus*, *Exterocrinus*, and *Vertigocrinus*. *Perimestocrinus teneris* Moore and Plummer was not assigned but was removed from *Perimestocrinus*.

Utharocrinus Moore and Plummer (1938, pp. 285–286) was introduced to accommodate the species *Delocrinus pentanodus* Mather, 1915. Subsequently, a number of species were assigned to *Utharocrinus*. However, in 1961a, Strimple (p. 20) proposed that the genus *Utharocrinus* be restricted to those forms having the characteristics of *D. pentanodus*, and assigned all other species of *Utharocrinus* to *Triceracrinus* or *Separocrinus*.

Triceracrinus (Bramlette, 1943) was placed into synonymy with *Utharocrinus* Moore and Plummer by Strimple (1950b). Knapp (1969, p. 381) revived the genus *Triceracrinus* and included Moore and Plummer's (1938) and Strimple's (1950b) species. Strimple (1961a) placed *Triceracrinus* in synonymy with *Perimestocrinus*. Strimple and Boardman (1971, p. 28), however, recognized the validity of the genus *Triceracrinus*.

The above discussion indicates that there is much confusion about the definitions and status of *Perimestocrinus*, *Utharocrinus*, and *Triceracrinus*. *Perimestocrinus* was the first of these genera proposed. Any species of *Utharocrinus* or *Triceracrinus* that subsequent research shows to have the characteristics of *Perimestocrinus* must go into the latter genus by priority.

Table 21 shows the status of additional species that have been assigned to *Perimestocrinus*, *Utharocrinus*, and/or *Triceracrinus*.

Delocrinus excavatus Weller was assigned to *Perimestocrinus* by Moore and Plummer (1940, pp. 210–213) because the specimen has two anal plates which differ slightly in size and considerably more in calcite crystal orientation and position. This species is retained in *Perimestocrinus* with some reluctance, however, as it deviates some from the type concept of that genus.

Range.—Lower Pennsylvanian (Morrowan)–Lower Permian (Wolfcampian). U.S.A. (Texas, Oklahoma, Arkansas, Kansas, Nebraska, Illinois, Nevada).

Genus SEPAROCRINUS Knapp, 1969

Type Species.—*Plaxocrinus praevalens* Moore, 1939.

Other Species Included.—None.

Diagnosis.—(After Knapp, 1969, p. 380). Cup low, basal plates small; plates tumid, posterior interradius narrow; notches present, no external ligament area; arms unknown.

Remarks.—Knapp (1969, p. 380) included *Utharocrinus facilis* Strimple 1950b, in *Separocrinus*. Though the cup of *U. facilis* bears a superficial resemblance to the cup of the type species of *Separocrinus*, there are no further similarities between the two species that might warrant placing *U. facilis* in *Separocrinus*. *U. facilis* has short, pentagonal, only slightly protruded first primibrachials; whereas *Separocrinus* has long, spinose first primibrachials. In addition, the former is highly ornamented whereas the latter is smooth, indicating that *U. facilis* should be removed to another genus, *Triceracrinus* Bramlette 1943, probably being the most suitable.

Genus TRICERACRINUS Bramlette, 1943

Type Species.—*Triceracrinus moorei* Bramlette, 1943, p. 550.

Diagnosis.—Basal and radial plates bulbous or spinose. No external ligament area present. Anal series in natural arrangement.

Other Species Included.—*Utharocrinus quinquactus* Moore, 1939; *U. fabulosus* Strimple, 1950b; *U. spinosus* Strimple, 1950b; *U. habitus* Strimple, 1950b; *U. facilis* Strimple 1950b; *U. granulosus* Strimple, 1939b; *Perimestocrinus bulbosus* Strimple, 1962c; ?*Lasanocrinus altamontensis* Strimple, 1950b.

Range.—Middle Pennsylvanian (Desmoinesian)–Lower Permian (Wolfcampian), U.S.A., (Texas, Oklahoma, Kansas, Iowa).

Triceracrinus facilis (Strimple), 1950b
Figs. 16d, e; 22j–l

Utharocrinus facilis Strimple, 1950b, p. 571, pl. 77, figs. 11, 12, 18–20.
Perimestocrinus facilis (Strimple) Strimple, 1961a, p. 24.
Separocrinus facilis (Strimple) Knapp, 1969, p. 380, text-fig. 1, 49.

Description.—Infrabasals 5, kite-shaped, nearly flat-lying and restricted to a shallow concavity where they form a pentagonal circlet, the interior half of which is covered by a round, crenulated columnar cicatrix. Basals 5, bulbous. AB, BC, and EA pentagonal, CD and DE hexagonal. Medial portions form basal plane of cup; some with pointed projections. Radials 5, epaulette shaped; C and D slightly modified to receive anal plates.

Anal X may be 4-sided, irregularly rhombic, barely touching the DE basal; an irregular pentagon, or an irregular hexagon in contact with the CD basal, this plate varying in size and position. Right tube plate may be rhombic, pentagonal, or hexagonal. Left tube plate small, hexagonal with facets.

Radial articular facets broad, sloping outward at about 30 to 45 degrees from the horizontal. Outer ligament area situated on outer walls of the radials. Outer marginal ridge wide; outer ligament furrow deep. Facets geniculate sharply upward at non-denticulate transverse ridge near cup summit such that the transverse ridges form the periphery of the cup. Oblique ridge non-denticulate, blunt. Lateral ridges high, and adsutural slopes steep. Lateral lobes well-defined and muscle areas slope inward to a deep central pit that connects to a deep V-shaped intermuscular notch by a short furrow.

Cup ornamented with regularly spaced, fine nodes and granules. There may be large nodes on the midportions of the basal plates, forming the basal plane of the cup.

Remarks.—The anal plates in the specimens studied appear to be highly variable elements that were in the evolutionary process of being excluded from the cup by migrating upward into the anal sac of the crown.

Material Studied.—Topotypes, USNM 6632; UNSM 11840–UNSM 11842; UNSM 16532–UNSM 16536, Melvern, Kansas.

Genus STENOPECRINUS Strimple, 1961a

Type Species.—*Perimestocrinus planus* Strimple, 1952, p. 787.

Diagnosis.—Cup low bowl-shaped, with rather deep and narrow basal concavity. Proximal portions of basals form steep walls of basal concavity and curve sharply to become visible in side view of cup; radials large, with proximal ends reaching

TABLE 21

SPECIES PREVIOUSLY ASSIGNED TO PERIMESTOCRINUS

SPECIES	*OCCURRENCE*	*CURRENT STATUS*
Hydreionocrinus noduliferus Miller and Gurley	Missourian; Missouri	*Type species of Perimestocrinus*
Hydreionocrinus nodulifer Moore and Plummer	Missourian; Missouri	Synonym of *P. noduliferus*
Hydreionocrinus granuliferus Miller and Gurley	Missourian; Missouri	*Perimestocrinus granuliferus*
Hydreionocrinus granulifer Moore and Plummer	Missourian; Missouri	Synonym of *P. granuliferus*
Eupachycrinus parvus Miller and Gurley	Missourian; Missouri	*Perimestocrinus parvus*
Perimestocrinus teneris Moore and Plummer	Morrowan; Ark., Okla.	*Perimestocrinus teneris*
Perimestocrinus nevadaensis Lane and Webster	Wolfcampian; Nevada	*Perimestocrinus nevadaensis*
Perimestocrinus oasis Webster and Lane	Wolfcampian; Nevada	*Perimestocrinus oasis*
Perimestocrinus ibexensis Strimple and Boardman	Wolfcampian Texas	*Perimestocrinus ibexensis*
Delocrinus excavatus Weller	Wolfcampian; Texas	*Perimestocrinus excavatus*
Perimestocrinus excavatus (Weller) Moore and Plummer	Wolfcampian; Texas	Synonym of *D. excavatus*
Delocrinus pentanodus Mather	Morrowan; Okla., Ark.	Type species of *Utharocrinus*
Utharocrinus sp. Lane and Webster	Wolfcampian; Nevada	*?Utharocrinus* sp.
Triceracrinus moorei Bramlette	Wolfcampian; Texas	Type species of *Triceracrinus*
Utharocrinus topekaensis Moore	Virgilian; Kansas, Iowa	*Triceracrinus topekaensis*
Lasanocrinus altamontensis Strimple	Missourian; Oklahoma	*?Triceracrinus altamontensis*

continued

into basal plane of cup, and with small notches at cup summit. Anal plates normal (primitive) to advanced. Arms uniserial, endotomous, with spinose primaxils. Anal sac taller than arms, terminating in a small platform surrounded by 7 large, outwardly directed spines.

Other Species Included.—*Perimestocrinus hexagonus* Strimple, 1952; *Perimestocrinus moselyei* Strimple, 1951a; *Plaxocrinus politus* Moore, 1939; *Stenopecrinus rugosus* Strimple, 1961a; *Stenopecrinus longus* Strimple and Watkins, 1969; *Perimestocrinus papillatus* Strimple, 1962c; *Perimestocrinus impressus* Moore and Plummer, 1940; *Stenopecrinus herophilus* Lane and Webster, 1966; *Stenopecrinus ornatus* Moore and Strimple, 1973.

Range.—Lower Pennsylvanian (Morrowan)–Upper Pennsylvanian (Missourian)–Lower Permian (Wolfcampian), U.S.A., (Texas, Oklahoma, Kansas, Nebraska, Iowa, Illinois, Utah).

Stenopecrinus sp. cf. _S. planus_ (Strimple), 1952
Figs. 21g–i

Remarks.—This species is represented by only a small cup with primibrachials attached on the A, B, and E rays. It was collected at Melvern, Kansas. *Stenopecrinus* is not known from the

TABLE 21
continued

SPECIES	*OCCURRENCE*	*CURRENT STATUS*
Utharocrinus fabulosus Strimple	Missourian; Oklahoma	*Triceracrinus fabulosus*
Utharocrinus granulosus Strimple	Missourian; Oklahoma	*Triceracrinus granulosus*
Utharocrinus habitus Strimple	Missourian; Oklahoma	*Triceracrins habitus*
Utharocrinus oreadensis Moore	Virgilian; Kansas	*Triceracrinus oreadensis*
Utharocrinus quinquactus Moore	Virgilian; Oklahoma	*Triceracrinus quinquactus*
Utharocrinus spinosus Strimple	Missourian Oklahoma	*Triceracrinus spinosus*
Utharocrinus facilis Strimple	Virgilian; Kans., Nebr.	*Triceracrinus facilis*
Perimestocrinus bulbosus Strimple	Desmoinesian; Oklahoma	*Triceracrinus bulbosus*
Perimestocrinus planus Strimple	Missourian; Oklahoma	Type species of *Stenopecrinus*
Perimestocrinus moseleyi Strimple	Missourian; Texas	*Stenopecrinus moseleyi*
Perimestocrinus hexagonus Strimple	Missourian; Oklahoma	*Stenopecrinus hexagonus*
Perimestocrinus impressus Moore and Plummer	Desmoinesian; Missourian, Texas	*Stenopecrinus impressus*
Perimestocrinus calyculus Moore and Plummer	Desmoinesian; Texas	*Stenopecrinus calyculus*
Perimestocrinus papillatus Moore	Desmoinesian; Oklahoma	*Stenopecrinus papillatus*
Perimestocrinus subtilis Moore	Virgilian; Oklahoma	*Vertigocrinus subtilis*
Perimestocrinus pumilis Moore and Plummber	Morrowan; Oklahoma	Type species of *Exterocrinus*

Stull Shale of Nebraska, but is found there in other stratigraphic units of both Missourian and Virgilian age.

Material Studied.—Hypotype, USNM 247906, from Melvern, Kansas.

Superfamily CROMYOCRINACEA Bather, 1890
Family CROMYOCRINIDAE Bather, 1890

Diagnosis.—Cup more or less globose, including forms with upflared infrabasals, which are visible from side; one to three anal plates in cup; arms uniserial or biserial, unbranched (*Cromyocrinus*) or branched on PBr1 in all rays, some younger forms also branching on SBr1 in some rays. Anal tube circular in section, small and short. Stem round transversely.

Genera.—*Cromyocrinus* Trautschold, 1867 (Lower Carboniferous - Lower Permian); *Aaglaocrinus* Webster, 1981 (Middle-Upper Pennsylvanian); *Aglaocrinus* Strimple 1961 [=*Tarachiocrinus*, 1962b (pro *Ataxiacrinus* Strimple, 1961, non Lyon, 1896)] (Middle Pennsylvanian–Lower Permian); *Dicromyocrinus* Jaekel, 1918 (Lower Pennsylvanian–Upper Pennsylvanian); *Ethelocrinus* Kirk, 1937, (Upper Pennsylvanian); *Goleocrinus* Strimple and Watkins, 1969, (Upper Mississippian–Middle Pennsylvanian); *Mantikosocrinus* Strimple, 1951c (Upper Mississippian); *Metacromyocrinus*

Strimple, 1961a (Lower Pennsylvanian–Middle Pennsylvanian); *Moapacrinus* Lane and Webster, 1966 (Lower Permian); *Mooreocrinus* Wright and Strimple, 1945 (Upper Carboniferous); *Paracromyocrinus* Strimple, 1961a (Middle Pennsylvanian); *Parulocrinus* Moore and Plummer, 1940 (Upper Pennsylvanian–Lower Permian); *Probletocrinus* Strimple and Moore, 1971a, (Upper Pennsylvanian); *Synarmocrinus* Lane, 1964b (Lower Pennsylvanian–Lower Permian); *Tyreiocrinus* Wright and Strimple 1945 (Early Carboniferous–Late Visean); *Ulocrinus* Miller and Gurley, 1890 (Middle-Upper Pennsylvanian): *Ureocrinus* Wright and Strimple, 1945 (Early Carboniferous, Visean).

Remarks.—Webster (1981) revised the family Cromyocrinidae to include the Ulocrinidae Moore and Strimple, 1973. In addition, Webster erected the genera *Mathericrinus* and *Aaglaocrinus* to include in the family as revised. Webster's suggestions are mostly followed here, pending further study.

Range.—Mississippian (Lower Carboniferous)–Permian. U.S.A., (Texas, Oklahoma, Kansas, Nebraska, Missouri, Iowa, Illinois, Colorado, Nevada); USSR. Lower Carboniferous (Visean)–Great Britain.

Genus PARULOCRINUS
Moore and Plummer, 1940

Type Species.—*Ulocrinus blairi* Miller and Gurley, 1894.

Diagnosis.—Crown moderately tall, having more than 10 biserial arms branching on PBr1 in all rays and PBr2 in some rays. Dorsal cup medium-sized, deep bowl-shaped to globose, no appreciable constriction at cup summit, typically no basal concavity, although there may be an almost imperceptible concavity or mild convexity; infrabasals subhorizontal; typically with 2 anal plates in cup, but proximal tip of right tube plate may enter cup.

Other Species Included.—*Phialocrinus americanus* Weller, 1909; *Mooreocrinus beedei* (Moore and Plummer), 1940, per Strimple, 1976; *Ulocrinus caverna* Strimple, 1949a; *Parulocrinus pontiacensis* Strimple and Moore, 1971a; *Parulocrinus planus* Moore and Strimple, 1973.

Remarks.—This genus is related to *Parethelocrinus* but usually has 3 anal plates in the cup rather than 2. Crowns of both genera have 16 biserial arms that bifurcate in similar fashion. Strimple (1961, p. 90) recognized that a separate genus may be required for more ornate forms. No specimens from the Stull Shale of Nebraska are strongly ornamented.

Range.—Lower Pennsylvanian (Morrowan)–Upper Pennsylvanian (Virgilian); Texas, Oklahoma, Kansas, Nebraska, Iowa, Illinois, Missouri.

Parulocrinus sp. cf. *P. blairi*
(Miller and Gurley), 1894

Figs. 24d–f

Ulocrinus blairi Miller and Gurley, 1894; p. 57, 58, pl. 5, figs. 16–18; Bather, 1900, pt. 3, p. 121, text-fig. 29–i; Strimple, 1961a, pp. 75, 77.

Parulocrinus blairi (Miller and Gurley), 1894; Moore and Plummer, 1940, pp. 360–363, pl. 19, fig. 5; Moore and Laudon (in Shimer and Shrock) 1944, p.175, pl. 64, fig. 37; Wright and Strimple, 1945, p. 227, fig. 2: Strimple, 1966a, p. 4; 1969, p. 63. Pabian and Strimple, 1980a, p. 17, pl. 5, fig. 13.

Description.—Infrabasals 5, confined to broad, shallow concavity. Infrabasal circlet large, pentagonal with crenulated columnar cicatrix and pentalobate lumen. Basal plane situated on proximal ends of 5 basals that curve upward in uniform quarter-round cross section. AB, BC, and EA basals pentagonal; CD and DE basals 6-sided to accommodate a very large, quadrangular radianal plate. Anal X heptagonal, situated between C and D radials and touching CD basal and radianal below. There is a notch between anal X and D radial for insertion of a tube plate. Radials 5, epaulette shaped, with D radial slightly modified by the radianal. The proximal tips of the radials reach from one-half to two-thirds the distance to the basal plane of the cup. The radials are nearly vertical but curve inward near the cup summit.

Radial articular facets wide, well-detailed. Outer marginal ridge sharp; outer marginal furrow not deep, but is prominent; it is about two-thirds as long as the corresponding radial plate is wide.

Ligament pit deep and about half as long as the corresponding radial is wide. Transverse ridge denticulate. Muscle areas depressed; central pit small, connecting to small intramuscular notch by a short, well-defined intramuscular furrow.

Cup plates smooth to finely granular. Sutures between plates sharp but not deeply impressed.

Remarks.—A trend toward the elimination of the RX plate can be seen. UNSM 8071 lacks this plate, but this is due to preservation as facets for the reception of this plate are on both the anal X plate and the C radial. This kind of arrangement is termed Developmental Trend B by Strimple (1960, pp. 249–250).

The specimens from the Stull Shale of Nebraska are either conspecific with or are very closely related to *Parulocrinus blairi*. More material is needed to identify this species.

Material Studied.—Hypotypes, UNSM 8071–UNSM 8072, Weeping Water, Nebraska; UNSM 12528, Ace Hill.

Genus AGLAOCRINUS Strimple, 1961a

Aglaocrinus Strimple, 1961a. *Tarachiocrinus* (pro-*Ataxiacrinus* Strimple, 1961a, Strimple, 1962b).

Type Species.—*Ethelocrinus magnus* Strimple, 1949b.

Diagnosis.—Cup broad, low, with shallow or flat base; anal X and RX in cup; arms 10 or more, branching on PBr1; surface mildly nodose or rough; sutures impressed; basals 5; radials 5, with long, plenary facets.

Other Species Included.—*Aglaocrinus konecnyorum* Webster, 1981; *Parulocrinus compactus* Moore and Plummer, 1940; *Parulocrinus marquisi* Moore and Plummer 1940; *Parulocrinus pustulosus* Moore and Plummer, 1940; *Ethelocrinus millsapensis* Moore and Plummer, 1940; *Erisocrinus tuberculatus* Meek and Worthen, 1865; *Hydreionocrinus verrucosus* White and St. John, 1868; *Aglaocrinus nacoensis* Webster, 1981.

Range.—Middle Pennsylvanian (Atokan)–Lower Permian (Wolfcampian), U.S.A., (Texas, Nevada, Oklahoma, Kansas, Missouri, Nebraska, Iowa, Illinois).

Aglaocrinus compactus (Moore and Plummer), 1940
Figs. 25a–f

Parulocrinus compactus Moore and Plummer, 1940, p. 36, pl. 18, figs. 5, 6, text-fig. 73; Moore and Laudon (in Shimer and Shrock) 1944, p. 175, pl. 64, fig. 37.

Aglaocrinus compactus (Moore and Plummer) Strimple and Cocke, 1973, p. 151, pl. 21, figs. 17–19; Pabian and Strimple, 1980a, p. 17, pl. 5, fig. 10; Webster, 1981, p. 1198.

Paracromyocrinus compactus (Moore and Plummer) Strimple, 1961a, p. 86; 1966, p. 5.

Description.—Infrabasals 5, large, kite-shaped, forming substellate circlet that is in shallow or nearly flat base. Columnar cicatrix round, crenulated, with pentalobate lumen. Basals 5, with proximal portions flat lying and, together with distal tips of infrabasals, make up basal plane of cup. Basals curve upward uniformly in a quarter round cross section, and the distal tips rise about half the cup height. AB, BC, and EA basals pentagonal; CD and DE modified hexagons to accommodate anal plates. Radianal large, rectangular; anal X 6-sided and touches only CD basal below. Radials 5, epaulette-shaped, with proximal tips extending about 2/3 the distance to the basal plane of the cup. Radials nearly vertical in attitude and curve inward sharply near cup summit.

Radial articular facets plenary, nearly flat lying. Outer marginal ridge well defined; outer marginal furrow narrow; ligament pit large and deep. Transverse ridge long, non-denticulate. Muscle areas flat, large, and on either side of faint central pit that appears to be divided into two parts. Intermuscular notch V-shaped, and connected to central pit by way of a short, wide intermuscular furrow.

Cup plates smooth to very finely granular. Sutures distinct, marked by quarter-round but not deep impression.

Material Studied.—Hypotypes, UNSM 12525–UNSM 12527, Ace Hill; UNSM 8000–UNSM 8002, Weeping Water; UNSM 17427, Folsom, Iowa.

Superfamily LOPHOCRINACEA Bather, 1890
Family LAUDONOCRINIDAE Moore and Strimple, 1973
Genus BATHRONOCRINUS Strimple, 1962c

Type Species.—*Bathronocrinus turioformis* Strimple, 1962c, pp. 27–28.

Diagnosis.—Cup shallowly conical. Infrabasals 5, visible in side view of cup; basals 5, 6-sided, upflared, moderately large; radials 5, dominant plates of cup. Articular facets peneplenary, sloping outward. Column round. Arms unknown.

Other Species Included.—*Hydreionocrinus deweyensis* Strimple, 1939a; *Hypermorphocrinus magnospinosus* Arendt, 1968; *Bathronocrinus wolfriverensis* Pabian and Strimple, 1974a.

Bathronocrinus sp.

Figs. 26c–e

Description.—Cup small. Infrabasals 5, with deeply impressed, round columnar cicatrix; distal portions visible in side view of cup. Basals 5; AB, BC, DE, and EA 6-sided; CD 7-sided, truncated for reception of anal X plate laterally, and C radial and right tube plate above. Radials 5; A, B, D, and E epaulette-shaped, C trapezoidal to accommodate radianal and right tube plates. Anal X large, hexagonal, bounded by CD basal below, D radial laterally, and rt plate above. Cup covered with fine nodes. Deep notches between radials. Posterior interradius deeply impressed, broad, giving cup hexagonal outline. Radial articular facets peneplenary. Outer facetal area vertical. Outer marginal ridge broad, outer marginal furrow deep. Ligament pit deep; transverse ridge sharp, non-denticulate. Lateral ridges sharp but lateral slopes low. Muscle areas sink gradually into a central pit made up of 2 smaller pits. It leads to a deep intermuscular notch via short intermuscular furrow. Oblique ridges faint.

Remarks.—The ornamentation suggests that this specimen has close affinities to *Bathronocrinus deweyeneis* (Strimple), other species of *Bathronocrinus* being inornate. The youthful stage of the specimen studied (hypotype, UNSM 16539) causes us to defer assignment of this individual to any species until it can be placed within a growth sequence.

Material Studied.—Hypotype, UNSM 16539, Melvern, Kansas.

Family STELLAROCRINIDAE Strimple, 1961a

Type Genus.—*Stellarocrinus* Strimple, 1940b, p. 1.

Diagnosis.—Crown widely expanded to mid-height, thereafter contracted; arms not apposed; cup low, truncate bowl-shaped, with broadly concave basal area; infrabasals 5, subhorizontal, confined to small area about column; basals 5, subhorizontal, confined to small area about column; forming sides of basal concavity and flexing sharply to form portion of lateral walls of cup; radials 5, consisting of wide, low elements with peneplenary radial articular facets. Anal plates 3 (*Heliosocrinus*) or only a single one remaining (*Stellarocrinus*) in cup. Anal tube stout, usually extending above arms, with termination a rosette composed of small plates covering the anal opening and 6 spinose perimeter plates directed horizontally. Arms may be uniserial (with cuneiform brachials) or biserial, branching once on PBr1 in all rays and usually having another isotomous division in all rays, with further branching in some species. Column pentagonal in geologically older forms, round in geologically younger forms, and composed of alternately expanded columnals.

Other Genera Included.—*Brychiocrinus* Moore and Plummer, 1940; *Heliosocrinus* Strimple, 1951c; *Brabeocrinus* Strimple and Moore, 1971a; *Celonocrinus* Lane and Webster, 1966.

Range.—Mississippian (Chesteran), Pennsylvanian (Morrowan–Virgilian), Permian (Wolfcampian), U.S.A., (Nevada, Texas, Oklahoma, Kansas, Nebraska, Iowa, Missouri, Illinois).

Genus STELLAROCRINUS Strimple, 1940b

Type Species.—*Cyathocrinus stillativus* White, 1880, p. 258.

Diagnosis.—Cup and crown with general characters of family and restricted to forms with biserial arms; notches between radial articular facets and advanced arrangement of anals consisting of single plate (radianal) on truncated tip of posterior basal, followed by two plates (probably anal X to left and RX to right).

Other Species Included.—*Whiteocrinus exculptus* Strimple, 1939b; *Stellarocrinus texani* Strimple, 1951a; *S. virgilensis* Strimple, 1951b; *S. petalosus* Strimple, 1961a; *Apollocrinus florealis* Moore and Plummer, 1940; *S. bulbus* Strimple and Watkins, 1969; *S. bilineatus* Strimple and Moore, 1971; *Aesiocrinus angulatus* Miller and Gurley, 1894.

Stellarocrinus stillativus (White), 1880
Figs. 21j, 24g–i

Cyathocrinus stillativus White, 1880, p. 258; 1880, p. 125, pl. 35, Figs. 3a, b.
Whiteocrinus stillativus (White) Strimple, 1939b, p. 5, pl. 1, figs. 1, 2, 9.
Stellarocrinus stillativus (White) Strimple, 1940b, pp. 1–3, pl. 1, figs. 1–4; Moore and Laudon 1943, p. 133, pl. 4, fig. 2; Moore and Laudon (in Shimer and Shrock) 1944, p. 157, pl. 57, fig. 13.

Description.—Infrabasals 5, kite shaped, forming circlet with crenulated columnar cicatrix with stellate lumen. Infrabasal circlet very prominent. Basals 5, each bearing a large, proximally situated ridge, the tips of each meeting the basal plane of the cup, and each with distally situated pair of smaller ridges that coalesce with a corresponding pair on adjacent radials. AB, BC, DE, and EA basals bulbous, spear-shaped, and CD hexagonal, being truncated for reception of radianal plate.

Radials 5, tapered pentagons. Their lower portions are bulbous and a large ridge runs perpendicular to each basal-radial suture about midway the length of each of these sutures and coalesces with a large ridge on each basal. C and D radials are separated by the radianal and smaller trapezoidal anal (radianal?) and right tube plates.

Radial articular facets peneplenary, nearly vertical to basal plane of cup. Outer marginal furrow wide, shallow, and coalesces with a deeper but indistinct ligament pit. Transverse ridge appears non-denticulate. Lateral ridge and lateral lobe form a long, semi-parabolic arc. Adsutural slopes steep, forming a deep notch between radials. Muscle areas ill-defined, and central area is raised slightly rather than having a central pit. Intermuscular notch deep, V-shaped.

Entire cup surface covered with fine, granulose ornamentation in addition to the system of ridges shared by adjacent basal and radial plates. Junctions between coalescing basal-radial sutures are deeply impressed and junctions between basal-radianal, anal X-RX-radial sutures are also deeply depressed.

Remarks.—The specimens at hand were collected just slightly higher in the section than the holotype of *Stellarocrinus stillativus*. Although the type species of *Stellarocrinus* was collected from Middle Virgilian strata, the genus is not well documented within that part of the section. *Stellarocrinus* is better documented in older Missourian strata. *Stellarocrinus* is not recognized from the Lower Permian (Wolfcampian) of Nevada, but the closely related genera *Celonocrinus*, and *Brabeocrinus*, extend into the Permian, (the former in Nevada, the latter in Oklahoma, Nevada, and Illinois).

Material Studied.—Hypotypes, SUI 37703, SUI 44064, and UNSM 16541, all from Melvern, Kansas.

Superfamily APOGRAPHIOCRINACEA
Moore and Laudon, 1943
Family APOGRAPHIOCRINIDAE
Moore and Laudon, 1943
Genus APOGRAPHIOCRINUS
Moore and Plummer, 1940

Type Species.—*Apographiocrinus typicalis* Moore and Plummer, 1940, pp. 118–123.

Diagnosis.—Dorsal cup low, bowl-shaped, and has gently tumid plates separated by impressed sutures. Base flat or shallowly concave, and infrabasals are down-flared or subhorizontal. There is a single anal plate with 2 facets.

Other Species Included.—*Apographiocrinus calycinus* Moore and Plummer, 1940; *A. decoratus* Moore and Plummer, 1940; *A. facetus* Moore and Plummer, 1940; *A. rotundus* Strimple, 1948; *A. obtusus Strimple, 1948; A. quietus* Strimple,

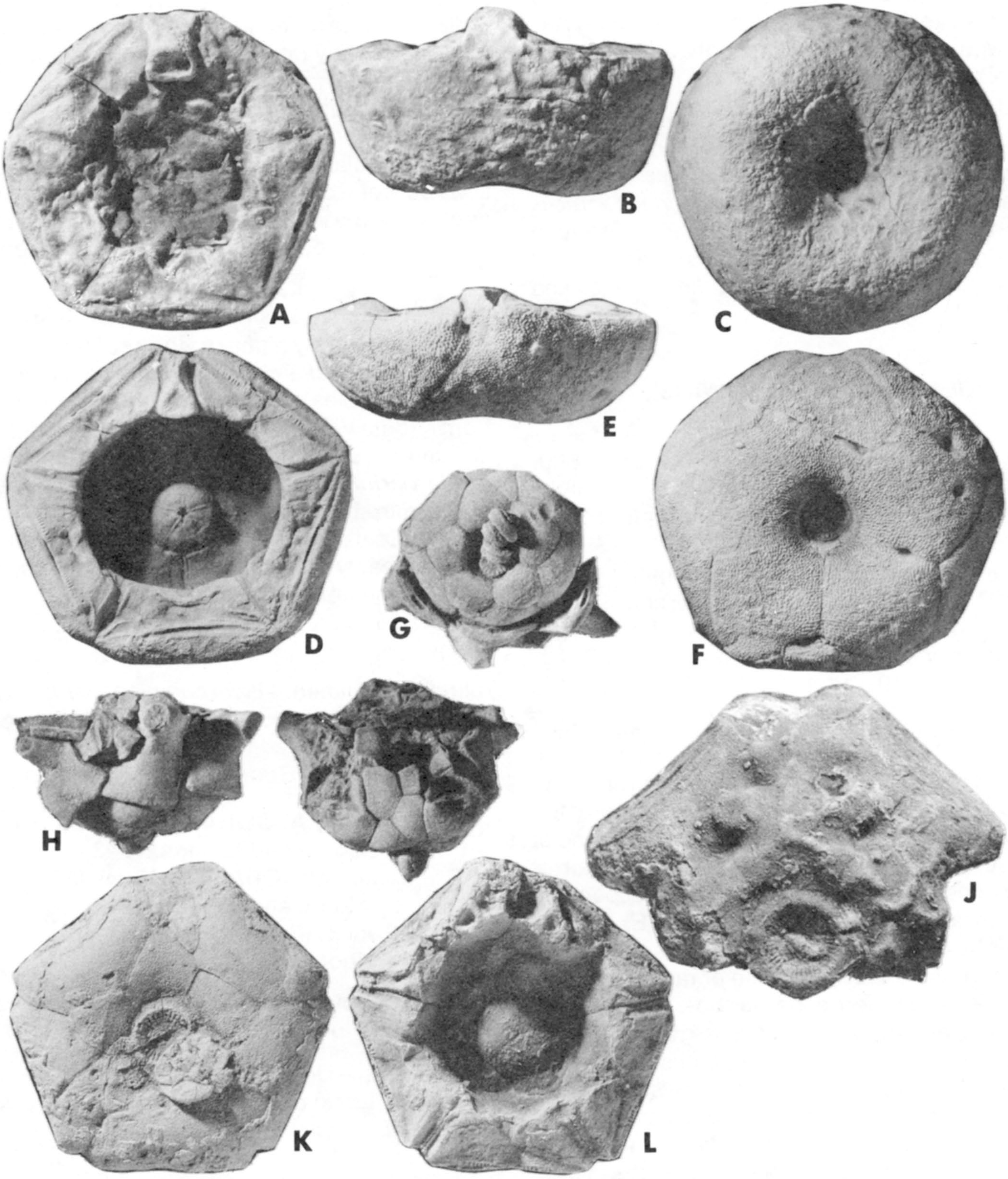

Fig. 21. A–C. *Graffhamicrinus subcoronatus* (Moore and Plummer), summit, posterior, and basal views of hypotype, UNSM 8054, from Weeping Water X3. D–F. *Graffhamicrinus* sp., basal, posterior, and summit views of hypotype UNSM 13316, from Ace Hill, X2. G–I. *Stenopecrinus* sp. cf. *S. planus* (Strimple), basal, anterior, and posterior views of hypotype, USNM 147906, from Melvern, Kansas, X3. J. *Stellarocrinus stillativus* (White), basal view of partial cup, hypotype, SUI 37703, from Melvern, Kansas, X3. K, L. *Plaxocrinus crassidiscus* (Miller and Gurley), basal and summit views of hypotype cup, SUI 37701, from Melvern, Kansas, X3.

1948; *A. angulatus* Strimple, 1948; *A. arcuatus* Strimple, 1949a; *A. virgilicus* Pabian and Strimple, 1974a; *Poteriocrinus (Scaphiocrinus) carbonarius* Meek and Worthen, 1862; *Delocrinus quinquelobus* Wanner, 1916; *D. verbeeki* var. *pumila* Wanner, 1916.

Remarks.—*Apographiocrinus* has not been observed in the Stull Shale of Nebraska or Iowa, although this genus is known from other Virgilian age strata of these areas.

Range.—Middle Pennsylvanian (Desmoinesian) -Upper Pennsylvanian (Virgilian), Lower Permian (Wolfcampian), USA: (Texas, Oklahoma, Kansas, Iowa, Nebraska, Missouri, Illinois, Michigan); Upper Permian, Indonesia.

Apographiocrinus virgilicus Pabian and Strimple, 1974a

Figs. 16b, c, 22d-f, 26l

Apographiocrinus virgilicus Pabian and Strimple, 1974a, pp. 276–277, figs. 3–5, tbl. 19.

Emended Description.—Emended to Pabian and Strimple, 1974a, pp. 276–277. Primibrachials axillary, long, epaulette-shaped, followed by at least 13 uniserially arranged, pinnulate secundibrachials.

Remarks.—One hypotype, UNSM 16529, has a tendency toward elimination of anal X plate. This plate is wedge-shaped and, proximally, barely in contact with the CD basal.

The ornamentation is not as coarse or as conspicuous on the specimens under study as it is on the holotype; however, it does appear to be distributed over more of the cup surface. The fine ornamentation covers the arms of an immature hypotype, UNSM 16529. In addition to the fine granules, a fine keel runs lengthwise on the primibrachials and secundibrachials of the immature specimen (Fig. 22d).

The arms of the immature hypotype, UNSM 16529, have 13 secundibrachials; distal brachials taper to points. Alternate brachials bear pinnules on the interior of each arm. The upper interior portion of every other brachial has a pinnular facet, and the interior or non-pinnulate brachials are modified to accommodate the pinnule which is upwardly directed when the arm is closed (Fig. 16f).

Material Studied.—Holotype, UNSM 7978, Ervine Creek Limestone Member of the Deer Creek Formation in the Shawnee Group of the Virgil Series. Weeping Water, Nebraska. Hypotypes, UNSM 16529–UNSM 16531; USNM 6632 all from Melvern, Kansas.

Superfamily SCYTALOCRINACEA Moore and Laudon, 1943
[Scytalocrinidae Moore and Laudon, 1943, p. 59] [=Scytalecrinidae Bather, 1899]
Family SCYTALOCRINIDAE Moore and Laudon, 1943

Type Genus.—*Scytalocrinus* Wachsmuth and Springer, 1879, p. 116.

Diagnosis.—Arms mostly 10, but may be 9 if anterior arm atomous. Anal sac tall, cylindrical, composed of small, polygonal plates, and not expanded distally.

Other Genera Included.—*Scytalocrinus* Wachsmuth and Springer, 1878 (1880) [=*Dactylocrinus* Sladen, 1878 (non Quenstedt, 1876); *Scytalecrinus* Bather in Lankester, 1900, (obj.)] *Anametocrinus* Wright, 1938; *Bollandicrinus* Wright, 1951; *Bridgerocrinus* Laudon and Severson, 1953; *Corematocrinus* Goldring, 1923; *Gilmocrinus* Laudon, 1933; *Haeretocrinus* Moore and Plummer, 1940; *Histocrinus* Kirk, 1940; *Hydriocrinus* Trautschold, 1867; *Hypselocrinus* Kirk, 1940; *Linobrachiocrinus* Goldring, 1939 [=*Linocrinus* Goldring, 1938, Aug. (non Kirk, 1938, April)]; *Logocrinus* Goldring, 1923; *Melbacrinus* Strimple, 1938; *Morrowcrinus* Moore and Plummer, 1938; *Ophiurocrinus* Jaekel, 1918; *Pegocrinus* Kirk, 1940; *Phacelocrinus* Kirk, 1940; *Priniocrinus* Goldring, 1938; *Roemerocrinus* Wanner, 1924; *Sostronocrinus* Strimple and McGinnis, 1969; *Tundracrinus* Yakovlev, 1928.

Range.—Middle Devonian–Upper Permian. USA, USSR, Europe.

Genus HYDRIOCRINUS Trautschold, 1867

Type Species.—*Hydriocrinus pusillus* Trautschold, 1867, p. 16.

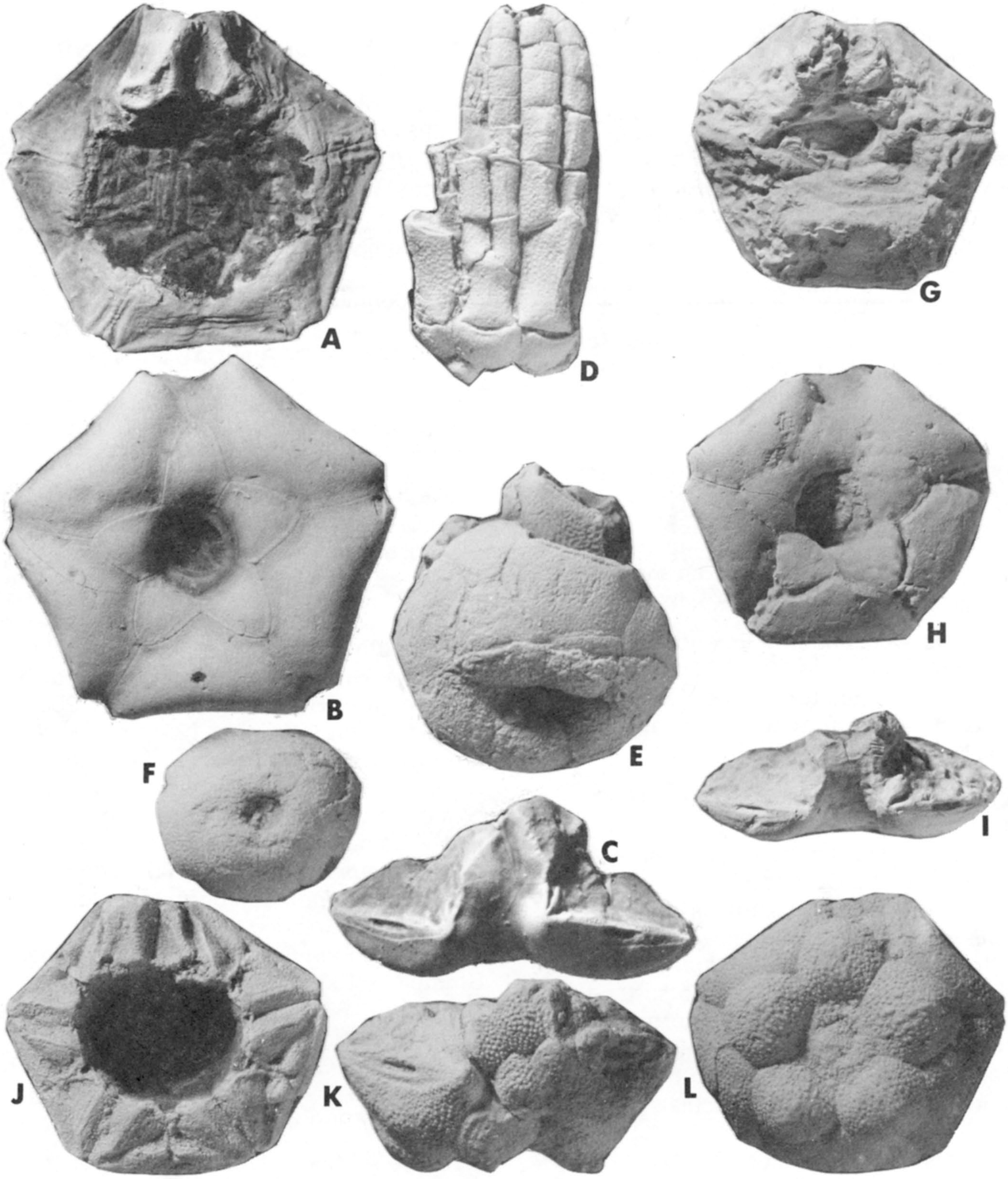

Fig. 22. A–C. *Sciadiocrinus humilis* Strimple, summit, basal, and posterior views of dorsal cup, hypotype, UNSM 8063, from Weeping Water, X2. D–F. *Apographiocrinus virgilicus* Pabian and Strimple, from Melvern, Kansas. D. Immature crown of hypotype, UNSM 16529, X4. E. Hypotype cup, USNM 5342 X4. F. Hypotype cup, USNM 5342, basal view, X3. G–I. *Vertigocrinus gloukosensis* (Strimple), summit, basal, and posterior views of hypotype, UNSM 16498, from Ace Hill, X2. J–L. *Triceracrinus facilis* (Strimple), summit, posterior, and basal views of topotype, UNSM 16532, X4.

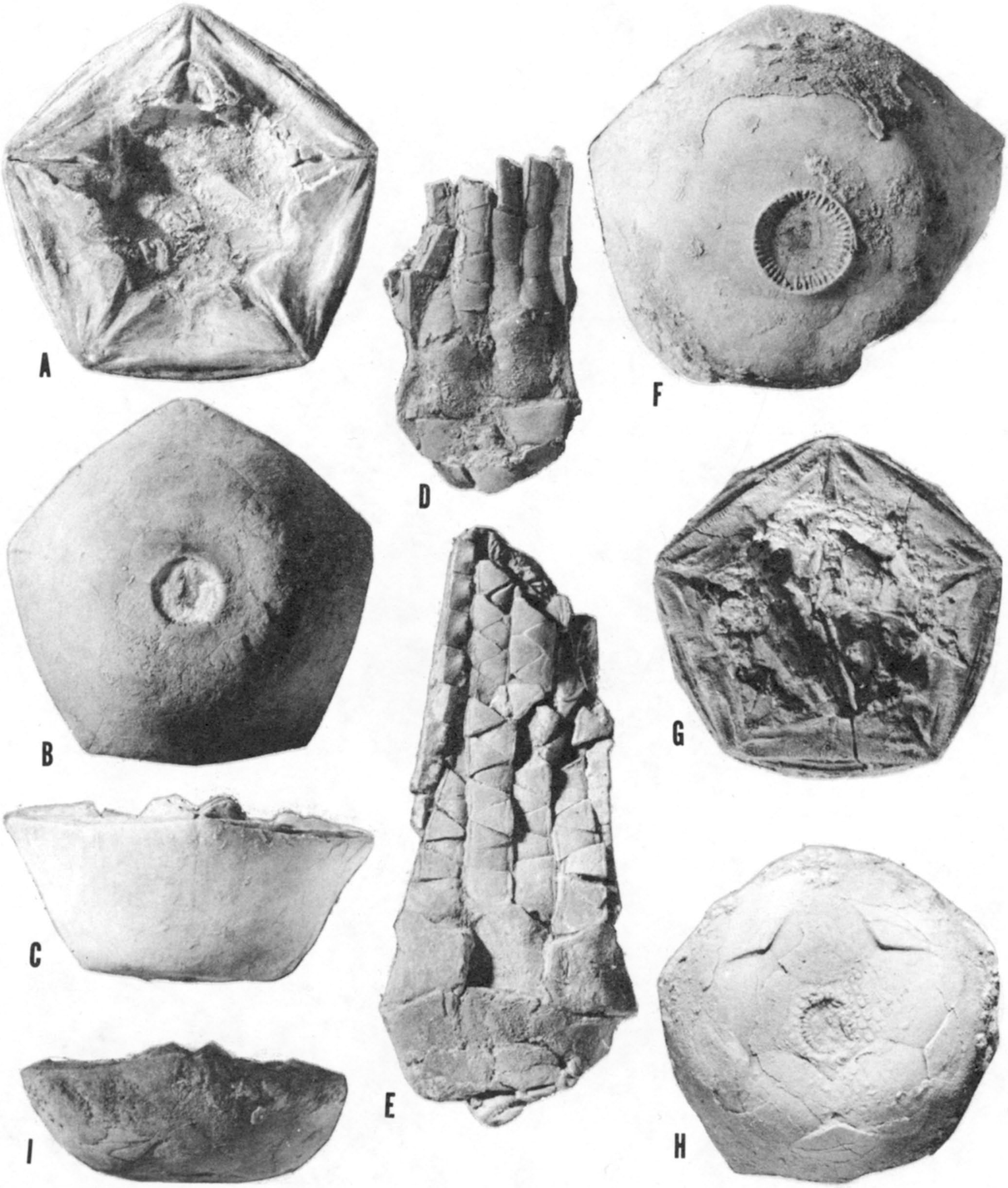

Fig. 23. A–F. *Erisocrinus typus* Meek and Worthen, A–C. Hypotype, SUI 37700, summit, basal, and posterior views, X2. D, E. Immature hypotype crowns, USNM 247908, X2, and USNM 247909, X2. Note uniserial arrangement of lower secundibrachials. F. Hypotype, USNM 247910, basal view, X2. G–I. *Erisocrinus* sp. cf. *E. terminalis* Strimple, hypotype, SUI 37704, X3. All specimens from Melvern, Kansas.

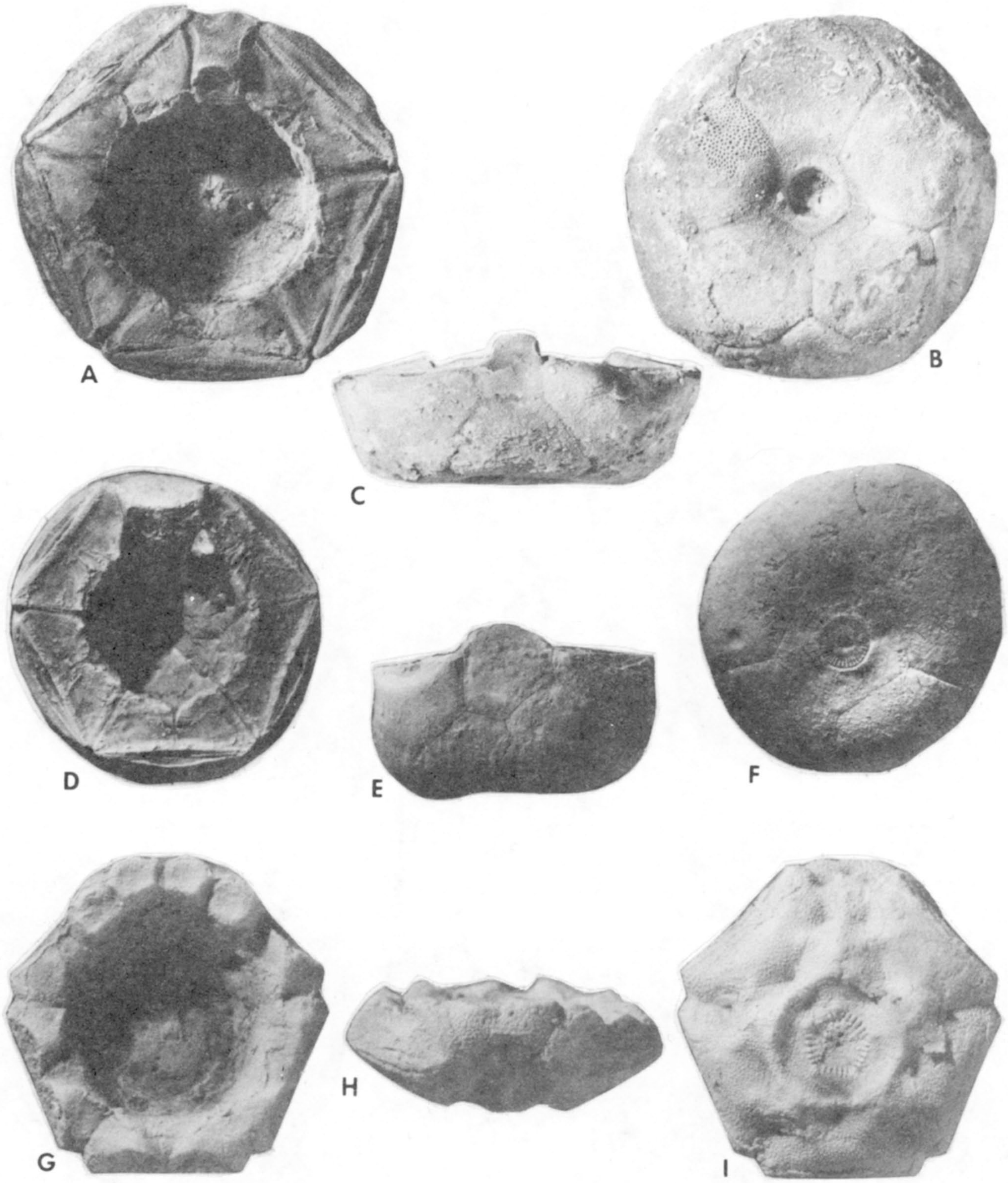

Fig. 24. A–C. *Cathetocrinus stullensis* (Strimple), summit, basal, and posterior views of topotype cup, USNM 247911, Melvern, Kansas, X3. D–F. *Parulocrinus* sp. cf. *P. blairi*, hypotype, UNSM 8071, summit, posterior, and basal views, from Weeping Water, X2. G–I. *Stellarocrinus stillativus* (White), summit, posterior, and basal views of hypotype, SUI 44064, X3, from Melvern, Kansas.

Diagnosis.—Cup high, conical. Infrabasals 5, visible in side view, radials 5, anals 3, below upper limit of radials. Arms 10.

Other Species Included.—*Cyathorcinus barumensis* Whidborne, 1896; *Hydriocrinus mjassoedowae* Yakovlev, 1926; *Mariocrinus mundus* Whidborne, 1899; *Scaphiocrinus plumifer* Whidborne, 1899; *Hydriocrinus ratingensis* Schmidt, 1930; *Hydriocrinus? rosei* Moore and Plummer, 1938; *Scaphiocrinus salebrosus* Whidborne, 1899; *Poteriocrinus tenus*, Whidborne, 1899; *Scaphiocrinus transcisus* Whidborne, 1899; *Hydriocrinus lorrainae* Strimple and Watkins, 1969; *Hydriocrinus turbinatus* Strimple, 1971b; *Hydriocrinus acehillensis* Pabian and Strimple, new species.

Range.—Upper Devonian–Upper Pennsylvanian, USA, USSR, Europe.

Hydriocrinus acehillensis Pabian and Strimple, new species

Figs. 25i–k

Description.—Dorsal cup tall, conical. Infrabasals 5, forming basally truncated cone. Columnar cicatrix sub-pentagonal, crenulated on periphery only with stellate lumen. Basals 5, AB, DE, and EA hexagonal, BC and CD heptagonal. BC basal with shoulder on upper left and CD with shoulder on upper right to receive pentagonal radianal. CD basal truncated distally to receive pentagonal anal X. Right tube plate borders RA below, anal X to the left, and C radial to the right.

Radials 5, epaulette-shaped, C and D separated by RA, anal X and RX plates. Radials flare outward slightly near summit of cup.

Radial articular facets plenary. Outer marginal ridges sharp. Outer ligament furrow broad, grading into large, deep ligament pit. Transverse ridge nondenticulate and connected to oblique ridge by a narrow, horizontal platform. Adsutural slope steep (about 80 degrees). Lateral ridge sharp; muscle areas slope inward steeply. Central pit small, distinct, marked by high, sharp boundary, and connected to V-shaped intermuscular notch by a very narrow but deep intermuscular furrow. Identical, except smaller, facets on anal X and RX plates. Cup surface smooth.

TABLE 22.
MEASUREMENTS OF HYDRIOCRINUS *ACEHILLENSIS* IN MM. DIMENSIONS AS SHOWN IN FIG. 2, TABLE 2.

Dimension	mm.
D_{PA}	12.1
W_{TR}	12.8
H_A	11.5
L_{AB}	6.3
W_{AB}	4.7
L_A	3.9
W_A	5.8

Remarks.—The Morrowan species *Hydriocrinus? rosei* Moore and Plummer, 1938, was thought to be the youngest species of this genus recorded in North America. The discovery of *H. turbinatus* Strimple in Late Missourian strata of Oklahoma necessitates a change in this interpretation. Strimple (1971b) further indicated that *H.? rosei* should perhaps be placed in *Phacelocrinus* Kirk. A hypotype specimen of *H. rosei* (UNSM 13784) from the Morrowan age Brentwood Limestone exposed near Fort Gibson, Oklahoma, is atypical of *Hydriocrinus* because anal X and RX plates are well above the cup summit, rather than forming a confluent plane and because the species has fused primibrachials in all rays. *H. lorrainae* Strimple and Watkins is from the Desmoinesian of Texas. *H. pusillus* and *H. lorrainae* have steeply parabolic cups; *H. turbinatus* and *H. acehillensis* have conical cups, the latter much higher relative to the former. Strimple and Watkins (1969, p. 199) suggested that *H.? rosei* is a progenitor to *Hydriocrinus* in North America, and this interpretation is also considered here.

Material Studied.—Holotype specimen, UNSM 12538.

Hydriocrinus? rosei Moore and Plummer, 1938

Hydriocrinus? rosei Moore and Plummer, 1938, pp. 238–241, Plate XIV, figs. 8a–d, fig. 9. Strimple, 1961b, pp. 306–307.

Remarks.—The specimen under study has all the characters of *Hydriocrinus? rosei*. The fused primibrachials are especially distinct.

Material Studied.—Topotype, UNSM 13794, collected by W. D. White, from the Brentwood

Limestone Member of the Bloyd Formation in the Morrow Series of the Lower Pennsylvanian. Keough Limestone Company Quarry, Fort Gibson, Oklahoma.

Family BLOTHROCRINIDAE Moore and Laudon, 1943
Genus ELIBATOCRINUS Moore, 1940

Type Species.—*Elibatocrinus leptocalyx* Moore, 1940a, p. 35.

Diagnosis.—Cup high, conical; infrabasals 3, basals 5, radials 5; 3 anals in cup; arms 10, long, cuneiform brachials; stem round; anal sac long, slender, composed of small plates in vertical series of 12.

Other Species Included.—*Elibatocrinus catactus* Moore, 1940a; *E. concinnulus* Moore, 1940a; *E. notabilis* Moore, 1940a; *E. hoodi* Strimple, 1961a; *E. elongatus* Webster and Lane, 1967; *E. elegans* Strimple and Moore, 1971a.

Range.—Middle Pennsylvanian (Desmoinesian) -Lower Permian (Wolfcampian), U.S.A., (Nevada, Texas, Nebraska, Kansas, Oklahoma, Illinois.)

Elibatocrinus sp. cf. *E. catactus* Moore, 1940a

Remarks.—Virgilian beds throughout Nebraska and Kansas contain numerous infrabasal circlets that are referred to *Elibatocrinus*. Most of these circlets are smooth, however, as compared to the types which have faint ornamentation. Since cups or crowns are lacking, it is not possible to readily assign these circlets to a species for other than comparative purposes.

Material Studied.—Hypotype, UNSM 13317, Ace Hill.

Order DISPARIDA Moore and Laudon, 1943
Superfamily ALLAGECRINACEA Carpenter and Etheridge, 1881
Family ALLAGECRINIDAE Carpenter and Etheridge, 1881
Genus KALLIMORPHOCRINUS Weller, 1930

Type Species.—*Kallimorphocrinus astrus* Weller, 1931.

Diagnosis.—(Modified after Strimple, 1966b, p. 105). Dorsal cup low, broad, with sharp delineation between basal and radial circlets and marked by tumidity of radial plates; basals 3, with sutures usually visible, form low disk; radials 5, of unequal size in maturity, articular facets marked by transverse ridge; orals none to [or] five; arms nine to thirteen, one arm on right posterior and left anterior radials, maximum number of arms on left posterior radial. Notch for anal plate pronounced. Open, lattice-like or, trabecular, composition of the plates is readily visible under low magnification.

Other Species Included.—*Kallimorphocrinus eaglei* (Strimple), 1966b; *K. barnettensis* (Strimple), 1975a; *K. erectus* (Strimple and Watkins), 1969; *K. strimplei* (Kirk) 1936; *K. lasallensis* (Strimple & Moore), 1971a; *K. copani* (Strimple), 1949; *K. constellatus* (Moore), 1940a; *K. dignatus* (Moore), 1940a; *K.* sp. cf. *K. bassleri* (Moore), 1940a; *K. pecki* (Moore), 1940a; *K. graffhami* (Strimple), 1948; *K. kylensis* (Strimple), 1948; *K. status* (Strimple), 1951; with reservation *K. donetzensis* Yakovlev, 1930; *K. pocillus* Weller, 1930; *K. illinoisensis* Weller, 1930.

Range.—Lower Pennsylvanian (Atokan)-Upper Pennsylvanian (Virgilian)-Lower Permian (Wolfcampian), U.S.A., Oklahoma, Texas, Kansas, Nebraska, Illinois, Indiana. Middle Carboniferous, USSR.

Kallimorphocrinus graffhami (Strimple), 1948
Figs. 25g, h

Allagecrinus graffhami Strimple, 1948, p. 3, pl. 1, figs. 1–11.
Isoallagecrinus graffhami (Strimple) Strimple, 1966, p. 104.
Kallimorphocrinus graffhami (Strimple) Lane and Sevastopulo, 1981, p. 256.

Remarks.—Six additional topotype specimens of this species are available including a fully mature individual with a portion of the arms attached as well as a small anal X preserved in place on the oblique left shoulder of the C radial. The distal portion of anal X is directed inward and covered by adjacent arms which produces a triangular appearance.

Although arms are added with age in three rays (A, B, and D), there appear to be differences in

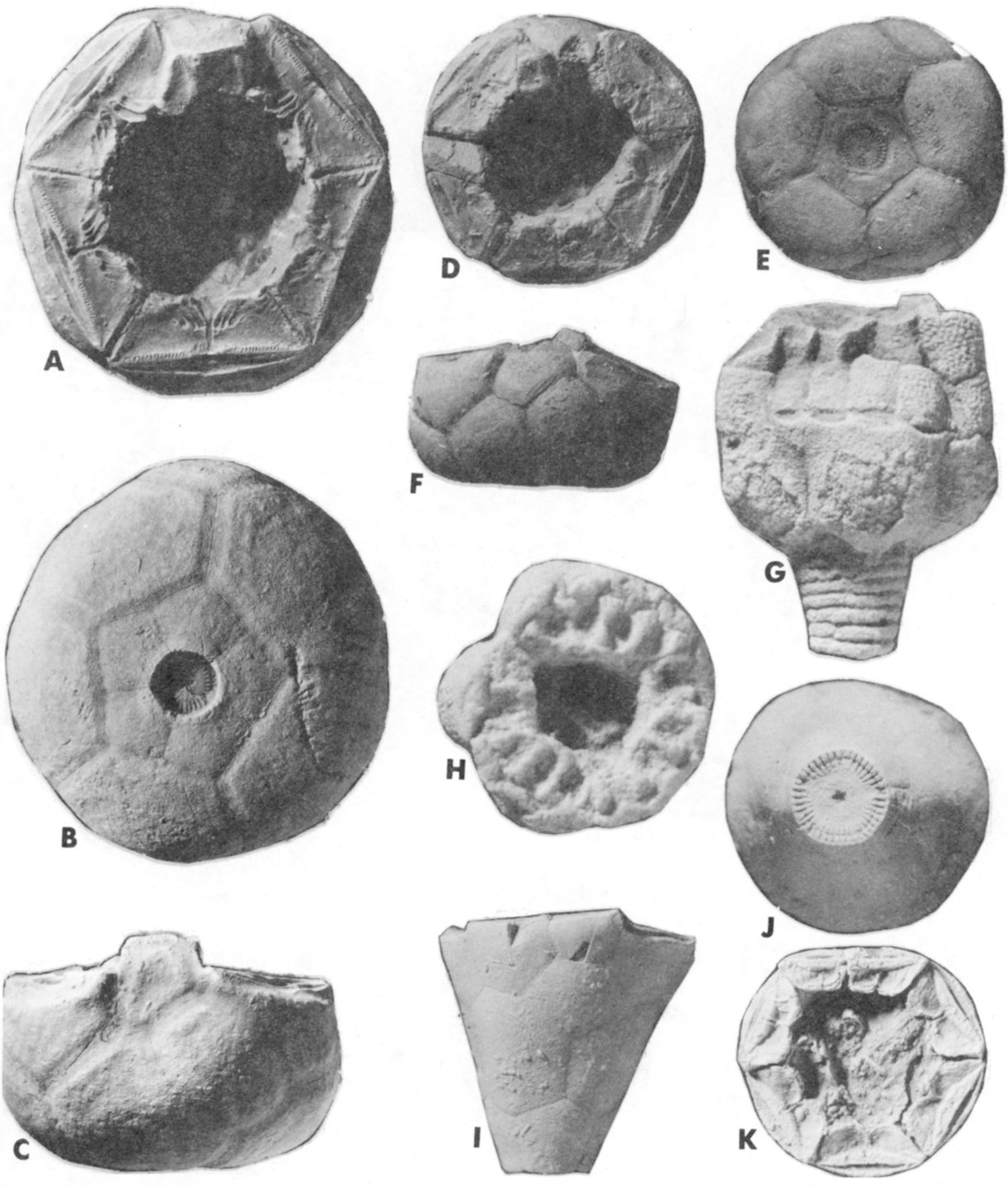

Fig. 25. A–F. *Aglaocrinus compactus* (Moore and Plummer). A–C, summit, basal, and posterior views of hypotype, UNSM 8073, from Weeping Water, Nebraska, X2. D–F. Summit, basal, and posterior views of hypotype, UNSM 8001, from Weeping Water, Nebraska, X2. G, H. *Kallimorphocrinus graffhami* (Strimple), from Melvern, Kansas. G. Hypotype, SUI 37706a, lateral view, X10. H. Hypotype, SUI 37706b, cup in summit view, X10. I–K. *Hydriocrinus acehillensis* Pabian and Strimple, new species. Holotype UNSM 12538, posterior, basal, and summit views, from Ace Hill, X3.

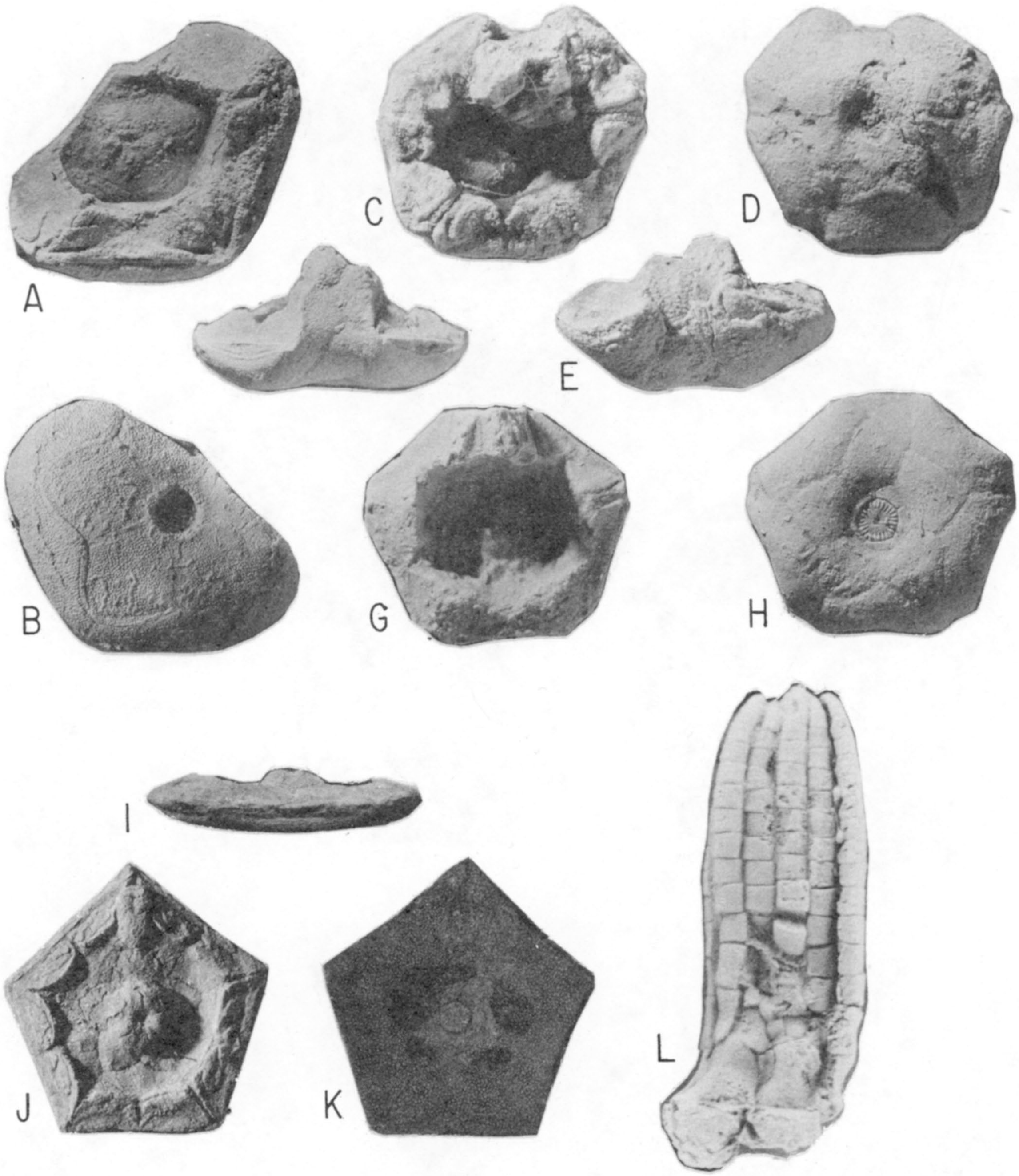

Fig. 26. A, B. *Pyndaxocrinus separatus* (Strimple), topotype, UNSM 11046, summit and basal views, from Melvern, Kansas, X2. C–E. *Bathronocrinus* sp. cf. *B. wolfriverensis* Pabian and Strimple, summit, basal, and posterior views of hypotype, UNSM 16539, from Melvern, Kansas, X5. F–H. *Plaxocrinus crassidiscus* (Miller and Gurley), posterior, summit, and basal views of hypotype cup, UNSM 16500, from Ace Hill, Nebraska, X2. I-K. *Kansacrinus discus* (Strimple), 1947, posterior, summit, and basal views of holotype, USNM-S-4733, from Melvern, Kansas, X2. L. *Apographiocrinus Virgilicus* Pabian and Strimple, left lateral view, hypotype UNSM 16529, from Melvern, Kansas.

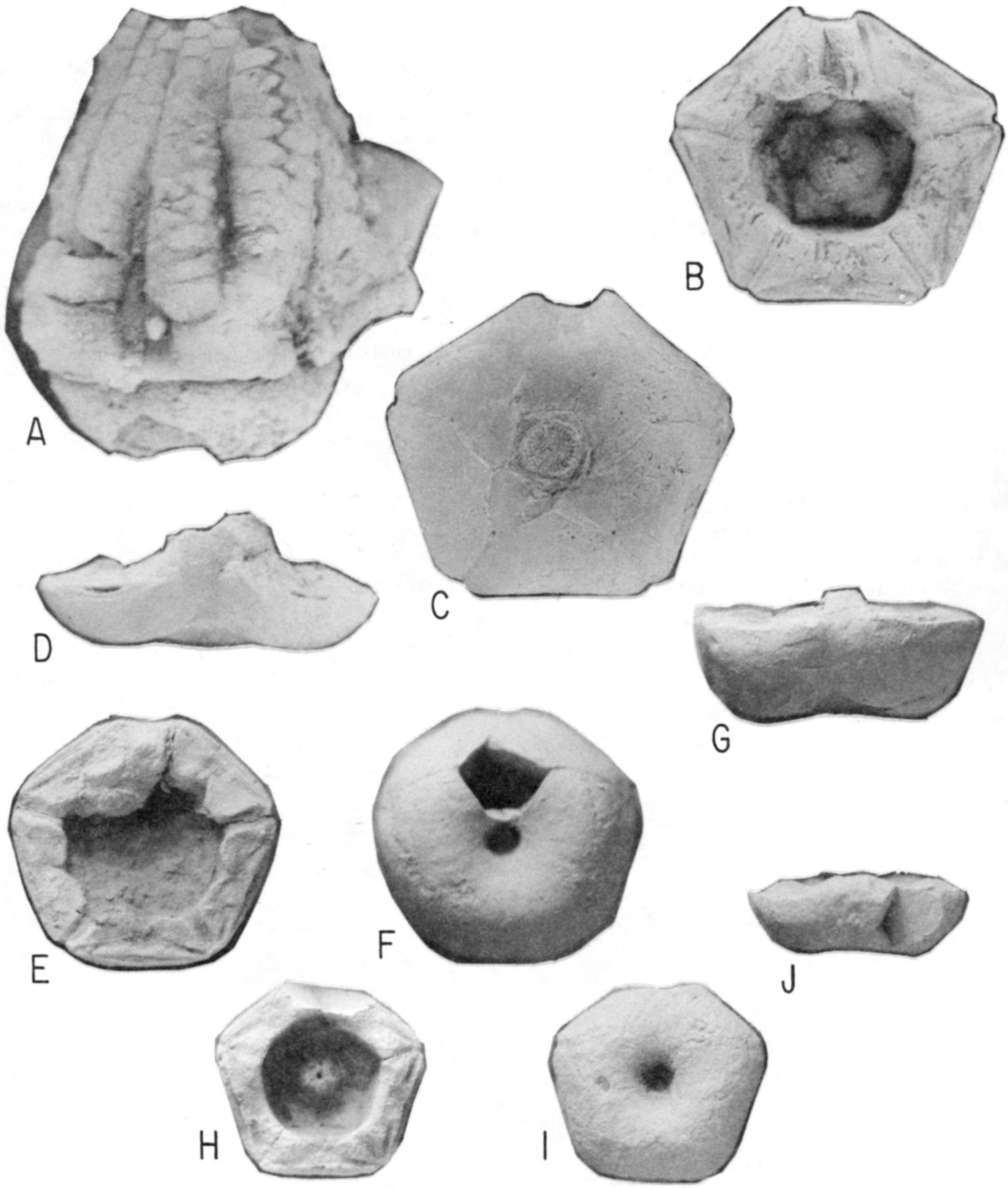

Fig. 27. A. *Delocrinus subhemisphericus* Moore and Plummer. Partial crown enclosed in limonitic matrix. Hypotype, UNSM 23344, from Melvern, Kansas, X2. B-D. *Sciadiocrinus* sp. cf. *S. disculus* Moore and Plummer, Hypotype, UNSM 22236, from Melvern, Kansas, X2. E–G. *Arrectocrinus iowensis* Pabian and Strimple, Hypotype, UNSM 17420, from Ace Hill, X2. H–I. *Sublobalocrinus kaseri* Pabian and Strimple, Hypotype, UNSM 17428, from Mills County, Iowa X2. J. *S. kaseri*, Hypotype, UNSM 17423, from Ace Hill, X2.

numbers between some species as demonstrated below:

TABLE 23
COMPARISONS OF SPECIES OF
KALLIMORPHOCRINUS

	Maximum cup diameter	Number of arms in each ray C ray	B ray	A Ray	E ray	D ray
K. bassleri	6.0mm	1	3	4	1	5
K. copani	5.3mm	1	2	1	1	2
K. grafthami						
(SUI37706a)	4.5mm	1	3	3	1	4
(SUI37706b)	4.0mm	1	3	3	1	4

Kallimorphocrinus graffhami appears to have stabilized with 12 arms; however, a specimen larger than 4.5mm would be likely to be gerontic for the species and could conceivably have 14 arms. With 12 arms, it is equivalent to a young adult of *K. bassleri* and distinct from *K. copani* which has 7 arms in maturity. *K. strimplei* is a small species but gerontic individuals may have developed as many as 12 arms.

Material Studied.—Topotypes (metatypes) SUI 37706, all collected by A. Allen Graffham at Melvern, Kansas.

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